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THE RELATIONSHIP BETWEEN SURVIVAL OF COLUMBIA RIVER FALL CHINOOK SALMON AND INRIVER ENVIRONMENTAL FACTORS

ANALYSIS OF HISTORIC DATA FOR JUVENILE AND ADULT SALMONID PRODUCTION: PHASE 11

FINAL REPORT

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This reanalysis of the draft by Hilborn et al. (1993b) of the investigation of chinook survival relationships was supported by the Bonneville Power Administration under Contract No. DE-B179-87-B035885 and Project No. 87-413-02 at the University of Washington, Seattle, Washington.

EXECUTIVE SUMMARY

This project analyzes in greater detail the coded-wire-tag (CWT) returns of Priest Rapids Hatchery fall chinook for the years 1976-1989 initially begun by Hilborn et al. (1993a). These additional analyses were prompted by suggestions made by peer reviews of the initial draft report. The initial draft and the peer review comments are included in this final report (Appendices A and B).

The statistical analyses paired Priest Rapids stock with potential downriver reference stocks to isolate in-river survival rates. Thirty-three potential reference stocks were initially examined for similar ocean recovery rates; the five stocks with the most similar recovery patterns (i.e., Bonneville Brights, Cowlitz, Gray's River, Tanner Creek, and Washougal) to the Priest Rapids stock were used in the subsequent analysis of in-river survival. Three alternate forms of multiple regression models were used to investigate the relationship between predicted in-river survival and ambient conditions. Analyses were conducted with and without attempts to adjust for smelt transportation at McNruy Dam. Independent variables examined in the analysis included river flows, temperature, turbidity, and spill along with the total biomass of hatchery releases in the Columbia-Snake River Basin.

Chi-square tests of homogeneity found highly significant ($P \ll 0.001$) differences in ocean recovery patterns between the Priest Rapids stock and the five best candidate downriver reference stocks identified by cluster analyses. Consequently, CWT returns were potentially confounded by unequal harvest rates when dowmiver stocks were used as references for the Priest Rapids Hatchery. Without information on harvest efforts, adjustments in CWT return numbers are impractical. Nonetheless, the anal yses continued to use the five candidate reference stocks and assess the robustness of conclusions based on choice of references.

Results of the multiple regression analysis in this final report differ from the preliminary results of the earlier Hilborn et al. (1993b) draft report. Reasons for the differences include: (1) new and updated CWT data from Pacific States Marine Fisheries Commission (PSMFC);

(2) the earlier analysis only considered flow as an independent variable, the new analysis considers several other variables as well as flow; (3) the earlier report did not attempt to adjust for transportation removal of Priest Rapids stock at McNary Dam, this report examines transportation adjusted counts; (4) the earlier report did not evaluate the robustness of the conclusion based on choice of reference stock, this new analysis assesses the consequence of reference choice. These differences are viewed as natural outcomes of a more detailed analysis the preliminary report was not intended to provide.

Estimated survival-covariate relationships differed slightly depending on whether the dependent variable used was the observed (expanded) CWT counts or the VPA estimated survival rates. In both cases, the results differed from the multiple regression model initially suggested by Hilborn et al. (1993 b). The findings varied little whether or not adjustments were made for transportation. Crucial, however, was the choice of reference hatchery used in the analysis. Results varied widely in the multiple regression analyses, dependent on choice of downriver reference stock or stocks (multiple regression model using a group of down-river stocks, as suggested by the Hilborn et al. draft (1993b)). Using the Cowlitz Hatchery stock as the downriver reference, none of the independent variables were correlated with estimates of adult survival of the Priest Rapids stock. With the other reference stocks, 2-5 independent variables were found to be correlated with estimated adult survival. All independent variables (i.e., flow, temperature, turbidity, spill, and hatchery contribution) were found to be significant in one or more analyses. Furthermore, no consistent pattern for the significance of the independent variables appeared across analyses that would suggest one factor was more influential than another.

This analysis of the 24 years of Priest Rapids hatchery returns yielded little insight into key in-river factors that may be influencing hatchery return rates. It may be possible to select a reference stock to yield any predictive multiple regression model desired. Hence, this investigative approach is not robust or reliable in identifying key mechanisms affecting survival of upriver smelt from release to age 2 or returning adult. Further studies should take this sensitivity into account when designing or analyzing other upstream-downstream paired investigations.

PREFACE

The focus of this effort was to develop a valid statistical framework to estimate adult survival rates from currently available Columbia River data and then through a multivariate regression analysis, explore interrelationships between these survival rates and environmental factors that affect smelt survival. Key to this approach was the recognition that many variables interact to determine the success of a juvenile outmigration and the ultimate adult returns. Phase I concentrated on developing methods and assembling the coded-wire-tag (CWT) data. A Phase I report covered the development and evaluation of two methods to estimate survival and presented criteria for data selection (Hilborn et al. 1993a). Under Phase II, a multivariate analysis of the Priest Rapids fall chinook stock was performed to investigate the relation of in-river factors to the observed juvenile survival rates.

The first draft of a Phase II report (Hilborn et al. 1993b) was titled, "The relationship between river flow and survival for Columbia River chinook salmon," and was found by the reviewers to be too narrow in scope. In response to those comments, the following report has been prepared. This report addresses most of the issues raised by the reviewers where data and statistical technique allowed. In addition to the independent variable flow, we included turbidity, temperature, spill, transportation, and total smelt release in the analysis.

By its very nature, the coded-wire-tag database undergoes change on at least an annual basis and occasionally more often. In preparing for the reanalyses, we found that the Oregon Department of Fish and Wildlife had recalculated the way sampling fractions were determined, which resulted in substantial changes to the expansion factor for many of the Oregon recoveries. In addition, other states and British Columbia made smaller, but nonetheless significant, changes to the historical data base. We delayed analysis until revisions were completed and the latest recovery data through the 1994 fishing season were available. For these reasons alone, the results were expected to differ from those of the earlier draft.

In response to the reviewers' comments, we decided to take the same conceptual approach to the analysis that had been taken earlier, but with increased depth. For example, we used the results of cluster analysis to locate those stocks with the most similar ocean catch distributions to the Priest Rapids stock, but we also performed statistical comparisons between the chosen reference stocks and the experimental stock (Priest Rapids hatchery). Our use of stocks at, or below, Bonneville Dam as references to the Priest Rapids stock was an attempt to control for ocean effects, but no reference stock was found to have homogeneous ocean recoveries with the Priest Rapids stock.

Unlike the previous draft, temperature, turbidity and the biomass of hatchery releases were shown to have the most consistent statistical relationships with survival, while flow was only occasionally significant. The reader should note that a study such as this one is based on statistical correlations and not cause-and-effect. This study should not be construed as a traditional experiment where there is an experimental group and a control group, differing only in a specific variable. The results do, however, shed light on probable relationships between smelt survival and in-river variables that we would recommend be the subject of future controlled experiments.

Appendix A contains the original draft of the research report prepared by Hilborn et al. (1993 b). Appendix B contains the peer review comments submitted in response to the original (Hilborn et al. 1993b) report and were the basis for this subsequent reanalysis. Some reviewers chose to make their comments in the draft copies of the text. To avoid a very large appendix, copies of their comments were not included in this report. Appendix K contains the peer review comments and responses to those comments for this version of the report.

Two important papers, “Return to the River . ..” (Independent Scientific Group 1996) and “Plan for analyzing and testing hypothesis (PATH)...” (Marmorek et al. 1996), have become available just prior to the publication of this report. Though both of these reports contain some similar topics, findings presented in this paper were considered unique and important.

1. INTRODUCTION

1.1 Background

Columbia River salmon have been fished for perhaps thousands of years. With the arrival of European settlers, the magnitude of the exploitation increased dramatically. At its peak, the catch of Columbia River salmon was in excess of 6 million fish from five species (Chapman 1986). The peak catches for each species occurred at different times over a period of about 30 years, centered around the 1890's. Chapman (1986) estimated that total return, catch, and escapement to the Columbia River was in the neighborhood of 7.5 million fish. The five species of salmonids native to the Columbia River are chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (O. *keta*), sockeye salmon (0. *nerka*), coho salmon (0. *kisutch*), and steelhead (O. *mykiss*). Chinook salmon are recognized as having two distinct life histories, ocean-type and stream-type. When discussing Columbia River chinook salmon, fisheries managers commonly refer to three races based on the time of the adult return migration into the river: spring, summer, and fall. Spring chinook have a stream-type Life history, fall chinook have an ocean-type life history, and summer chinook have a mixture of the two, depending on spawning location. After emergence, stream-type juveniles spend one year in fresh water, generally the upper reaches of the tributary streams, before migrating to the ocean, and are known as "yearlings" when they outmigrate. Fall chinook (ocean-type) are termed "subyearlings" and outmigrate during the first summer after emergence.

Beginning about 1900, Columbia River salmon catches began to show a downward trend, although the annual fluctuations typical of most salmon runs continued to occur. The adults that migrate into the river during the summer have suffered the most (Thompson 195 1), declining to very low numbers, recovering slightly in 1959, and then declining again (Chapman 1986). Most authorities (e.g., Laythe 1948, NWPPC 1986) have attributed the decline in chinook runs to a wide variety of causes including deforestation, farming, mining, pollution, overfishing, unscreened water diversions, cattle ranching, and construction of dams--the last considered to be the major contributor. To overcome these problems, Laythe (1948) suggested a mitigation program in the lower river which included screening water diversions and habitat protection, as well as the construction of fish hatcheries. The hatcheries and the lower-river efforts were never fully implemented; and by the mid- 1970's, the stocks of chinook salmon migrating to the mid-Columbia were at extremely low levels. The use of hatcheries to increase the run sizes had proved relatively unsuccessful.

Studies were initiated on the surviving salmon stocks in the mid-Columbia River from Bonneville Dam to Grand Coolee Dam and up the Snake. River to above Lower Granite Dam. Raymond (1969, 1979, 1988) studied the consequence of impoundment of water behind dams and the effects it had on the time it took juvenile salmonids to migrate downstream through these reaches. Two major findings from his work were (i) wild stocks had better survival than hatchery-produced fish, and (ii) impoundment of water behind darns slowed outmigration and was thus thought to reduce survival. As a result of water impoundment behind dams, several environmental variables were impacted. During the spring and summer months, the water temperature was raised, the big spring freshet was reduced (but not totally eliminated), and the turbidity of the water was reduced. In addition, all of the river water could not pass through the hydropower turbines; thus, some was spilled, allowing some juvenile fish to move over the spillway instead of through the turbines. Further, to mitigate for mortality at dams, juvenile salmonids were collected at several dams and transported below B onneville Dam.

The direct effect of river discharge on the downstream movement of salmon fry has been studied by a number of investigators (Irving 1986, Giorgi et al. 1990, Raymond 1968, Park 1969) with varying results. Giorgi et al. (1990) investigated the relation of flow to travel time of subyearling chinook salmon and were unable to conclude that changes in river flow were related to changes in travel time. However, they did note that fish moving out in the early part of the summer had higher survival rates than later outmigrants. Raymond (1969) found that the John Day Reservoir increased the travel time of outmigrating smelts from 14 days to 22 days for that stretch of river. Park (1969) concluded that, with the advent of dams, the peak spring flows were reduced, turbidity decreased, and predation and disease increased. He further concluded that "an almost continuously impounded river, with resultant trends toward warming water and increased numbers of predators, and other complex changes in the environment, could eventually jeopardize the existence of the chinook salmon in the [mid] Columbia River."

In an effort to shed light on a complex situation and prevent continuing erosion of Columbia River salmon abundance, the United States Congress passed the Pacific Northwest Electric Power Planning and Conservation Act in 1980 which authorized the states of Idaho, Montana, Oregon, and Washington to create an entity to plan for two important resources in the Columbia River Basin--electricity, and fish and wildlife. The entity created was the Pacific Northwest Power Planning Council, best known as the Northwest Power Planning Council. To emphasize the importance of fish and wildlife, Congress mandated that the Council develop the Columbia River Basin Fish and Wildlife Program before developing a power plan.

The Council established the doubling of the abundance of the salmonid runs in the Columbia River as a primary goal of its Fish and Wildlife Program. Achievement of this objective could result from: (i) an increase in the production of hatchery salmon, (ii) increases in the production of natural spawning salmon, and (iii) increase in the downstream survival of smelts, with all three factors likely to be involved in a truly successful stock rebuilding effort. Many management actions have been taken in an attempt to increase downstream survival, including: (i) fish bypass facilities--screens that divert juvenile salmon from turbines, passing them through the dam in a separate water system; (ii) transportation of smelts, collected at the lower-end of the fish bypass facilities, via barge to below Bonneville Dam where they were returned to the river; (iii) increased flow during periods of heavy smelt migration--augmenting the spill of water over the dams and thus moving more smelts over rather than through the darns; (iv) predator control--reducing the population of northern squawfish (*Ptychocheilus oregonensis*) in the reservoirs. Each of these actions were directed toward increasing the survival of fish from the time-of-release at the start of the downstream migration until they entered the lower river below Bonneville Dam. While fish bypass facilities have been evaluated using fin-clipped or freeze-branded fish, and transportation evaluated using coded-wire-tags; to date, no attempts have been made to evaluate predator control efforts, flow augmentation, or other abiotic variables.

This study, using historical returns of coded-wire-tagged hatchery fish from Priest Rapids hatchery, 1976-89, investigated possible relationships between survival of chinook smolt and in-river conditions during outmigration. The purpose of this study was to shed light on those river conditions and operations that may substantially impact salmonid survival. Specifically, we chose to look at temperature, flow, turbidity, transportation, spill, and total annual hatchery releases into the Columbia river (by weight).

1.2 River Conditions Considered in This Study

The relation of turbidity and smelt survival has been debated for years. A contrivers y between recreational and mining interests on the Rogue River resulted in a study of the impact of turbidity (Ward 1938), concluding that the added suspended sediment would not adversely impact salmon in the Rogue River. Recent studies have confirmed that turbidity (except at high levels) does not cause direct mortality (Servizi and Martens 1992). However, juvenile salmon that have a choice will avoid turbid water (Bisson and Bilby 1982). Pulses of sediment can cause downstream displacement of juvenile salmon (Berg and Northcote 1985) but the fish soon acclimatized to the higher turbidity. Predator avoidance appears to be enhanced by increased turbidity (Gregory 1993, Junge and Oakley 1966). Feeding behavior of juvenile salmon changed with turbidity. Juvenile salmon underwent a log-linear reduction in reaction distance to food as turbidity increased, (Gregory and Northcote 1993, Gregory 1988). Finally, turbidity can be lethal when the concentration of sediment in the water reaches levels sufficient to cause suffocation (Sigler 1988). These more than justify its inclusion in this analysis. Turbidity was measured daily by secchi disk on the south side of McNary Dam, upstream of the fish ladder.

A second factor considered was the total weight of hatchery smelt releases of steelhead, coho, and chinook salmon for the entire Columbia River Basin. The probable impact was considered to be one of density dependence (Ricker 1954, 1975) where survival and total release would be inversely correlated. There is some evidence for this in the case of coho salmon (McGie, 1984, Pearcy 1992). Coho smolt releases were shown to be significantly correlated with reductions in survival. The mechanism was thought to be limitations on the food supply in the coastal regions of the ocean.

A third environmental factor, flow velocity, was reduced with the construction of dams. There is evidence that the downriver movement of the juvenile salmon has been slowed by that construction (Raymond 1979). In the Columbia River, below the confluence with the Snake River, Raymond (1979) found that migration rates for juveniles were on the order of 40 to 55 km/day for free-flowing and impounded stretches at moderate river flows (about 8,500 m^3/sec.), and in the range of 24 to 27 km/day at low flows (about 4250 m^3/sec.). Although the hypothesis that flow and travel time are directly related (Berggren and Filardo 1993) is viewed as a basis for present river management, the situation is not as clear as might be hoped because of apparently confounding effects. For example, travel time is related to the condition of juvenile salmon at the time of migration. Their physiological condition is related to water temperature which, in turn, is related to the time of year (Giorgi et al. 1988). The later in the year, the faster the juveniles appear to outmigrate (Chapman et al. 1991). Flow at McNary Dam is estimated by the Army Corps of Engineers from dam operation specifications.

Temperature is a widely recognized environmental variable that can have a major impact, both positive and negative, on salmon survival. Brett (1952) performed laboratory studies to determine the temperature tolerance of young salmonids. In general, the upper lethal temperature for Pacific salmon (the old genus *Oncorhynchus*) was about 25 degrees Celsius. The lower lethal Limit was 4 degrees Celsius or higher if the fish were transferred from high to low temperatures without acclimatization. Between the lethal extremes, temperature plays a major role in metabolism. For sockeye salmon, the optimum temperature is about 15 degrees Celsius. Above this temperature, the metabolic rate diminishes, as does feeding and growth rates (Brett and Groves 1979, Brett 1979). Many investigators have done field studies to investigate the effects of temperature on salmonids (examples include: Smit, et al. 1981, Kope and Bostford 1990, and Holtby et al. 1989), and in general, warm temperatures near the lethal limit are very detrimental for juvenile fish. Temperature measurements were taken from the scroll case at McNary Dam.

Water is spilled over the spillways when the flow is greater than the generator capacity of a dam or a conscious decision is made to allow water to pass over, rather than through, the darns. When water is spilled, a fraction of the downstream migrants go with the spill. For spring chinook salmon smelts, this fraction is often assumed to be proportional to the fraction of water spilled versus what goes through the dam. Of the three ways for juvenile subyearling chinook salmon to pass the Bonneville Dam (turbines, spillway and fish by-pass), the spillway causes the least mortality (Ledgerwood et al. 1990). Spill reduces the proportion of fish exposed to turbine passage, thereby reducing mortality rates. In contrast, increase in the amount of spill will cause an increase in nitrogen saturation levels, which has been shown to be lethal at high levels to juvenile salmon (Dawley et al. 1975) in laboratory conditions. Though not proven in the field, this potential upper-boundary condition and the general effect of spill on salmon survival warrants its inclusion in the anal ysis. Spill at McNary Dam is estimated by the Army Corps of Engineers from dam operation specifications.

Most studies of juvenile salmon and survival have concentrated on in-river measurement and comparison, primarily using freeze branded fish to measure travel times. Such studies cannot examine the survival of *smelts* after they pass through the h ydropowers ystem. A potential source of such data is coded-wire-tag (CWT) data. Since the early 1970s, thousands of groups of hatchery and wild fish have been tagged in the Columbia Basin. The commercial and recreational fisheries, as well as the hatcheries and spawning grounds, have been routinely sampled for returning adult salmon with the CWTS. These data are then used for many purposes including the Pacific Salmon Commission working groups to estimate survival of Columbia River stocks.

2. MATERIALS AND METHODS

2.1 Data

Coded-wire-tags (C WTs). The CWT is a so-called “mass” mark and is applied to large numbers of fish using the same tag “code.” CWTs are not useful as tags for the identification of individual fish. CWTS are inserted into the nose cartilage of the fish using a device specifically designed for the purpose (Jefferts et al. 1963). Simultaneously, the adipose finis removed to indicate the presence of a CWT. When a tagged fish is recovered, the origin of that fish can be identified from the retrieval of the tag. The data that are obtained from the CWT tagging program includes location of original tagging, date of tagging, date and location of recovery, as well as many other items such as size of fish at tagging, species, number tagged, and how recovered. These data are accumulated and stored electronically by the Pacific States Marine Fisheries Commission (PSMFC). The PSMFC makes these records publicly available.

The CWT data form the basis for estimating survival of each tagged group used in this study. Thus, it is important that the data be as complete and as accurate as possible. The information on CWTS at the time of application and release is considered by most to be accurate. The recovery data are another matter; agencies charged with recovery efforts attempt to sample a specific fraction (usually 20 percent) of each fishery and then expand the number of recoveries by the sampling fraction. Though possible for most commercial fisheries, sampling sport fishing recoveries is more difficult, given the very large number of possible landing sites as well as the independent nature of each person fishing and independent use of the captured fish. In addition, hatchery detection efforts are subject to many variables including time demands on hatchery personnel. Spawning ground surveys also present problems; water clarity, state of decomposition of carcasses, etc. In summary, the commercial fishery sampling effort probably provides the best data on recoveries and, coincidentally, the most abundant CWT recovery data.

The commercial fishery data are also subject to criticism. In particular, the way in which the data are tabulated as to location of capture or location of landing can result in biases being introduced into the data sets. Also, the data undergo changes through time due to the correction of errors or the recalculation of sampling fractions, to mention two examples. As a result, the data kept by PSMFC will change from time to time. During late 1994 and early 1995, the recovery data set underwent some major revisions. The revised data set was substantially different from the earlier data, especially for the Oregon coastal recoveries with smaller changes in data from other states and British Columbia. We were alerted to these changes and delayed analysis until the changes were implemented.

Environmental covariates. Variables included temperature, turbidity, flow, spill, and percent spill. The data were obtained from the United States Army Corps of Engineers (USCOE) Annual Fish Passage Reports, 1976-1989. Specifically, we used data from McNary Dam for the months of April through August. The data were obtained as daily observations, permitting us to do detailed analysis using different time scales (e.g. daily, weekly or monthly). Plots of weekly averages of flow, spill, turbidity and temperature (Figures 1-4, respective y) show that releases for Priest Rapids occurred under widely varying conditions. How these conditions are characterized is somewhat arbitrary, and only two methods were explored. One is to take an average value over a specified time period. The value of each river covariate averaged over the 28 days following each tag release at Priest Rapids (Table 1) display large standard errors.

Figure I: Average weekly flow at McNary Dam. 1976-1989. Releases at Priest Rapids are indicated by dots.

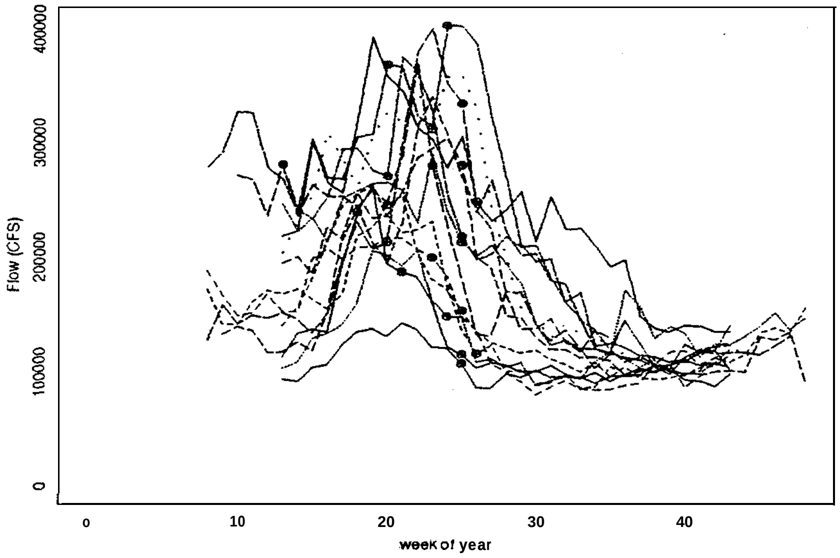


Figure 2: Average weekly spill at McNary Dam. 1976-1989. Releases at Priest Rapids are indicated by dots.

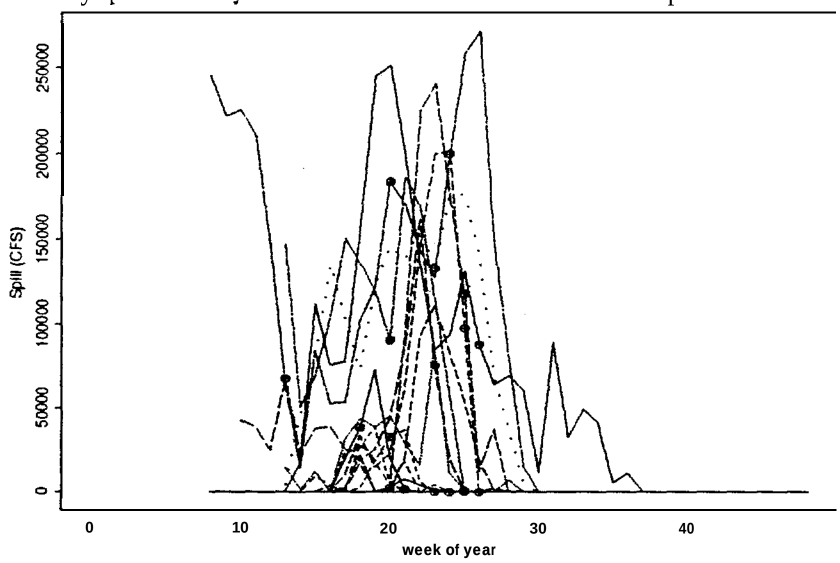


Figure 3: Average weekly **turbidity** at McNary Dam. 1976-1989. Measurements were taken with a **secchi** disk, Releases at Priest Rapids are indicated by dots.

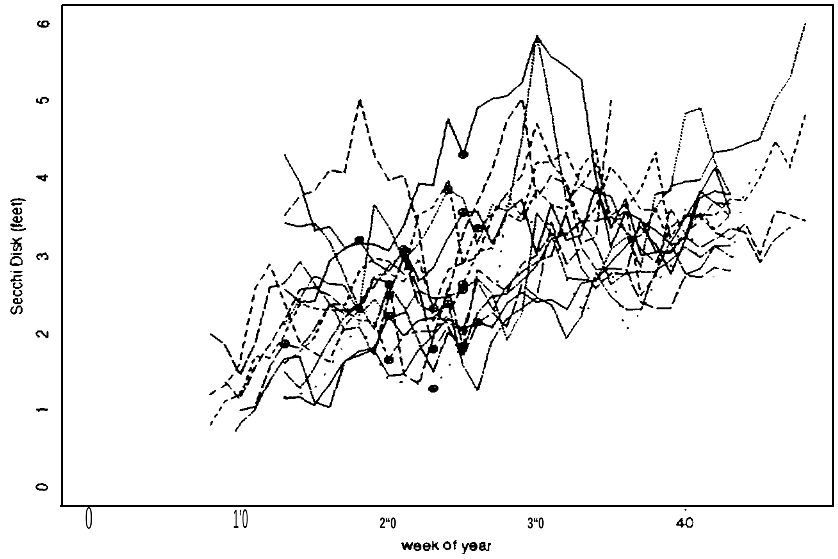


Figure 4: Average weekly temperature (Celsius) at McNary Dam. 1976-1989. Releases at Priest Rapids are indicated by dots.

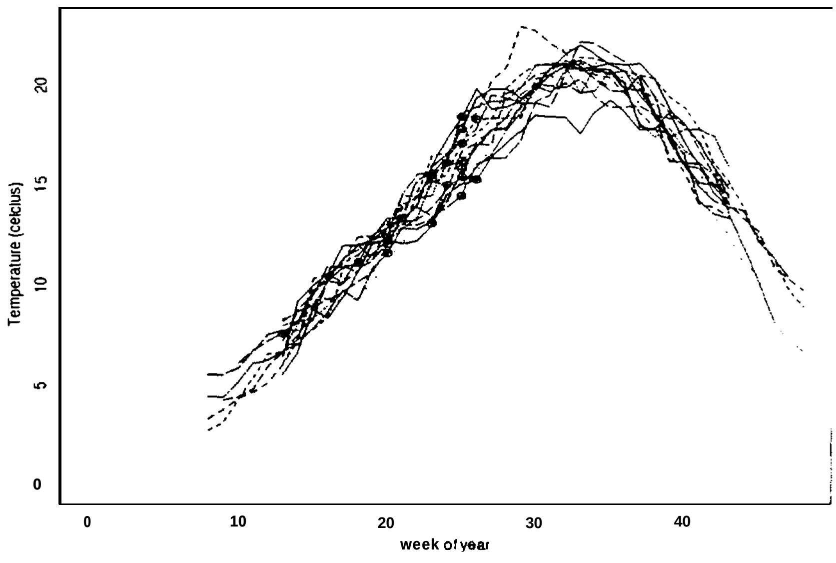


Table 1: Monthly average and standard errors of selected river covariates at McNary Dam after release from Priest Rapid's hatchery, 1976-1989.

Release		flow	flow Se,	spill	Sp ill se.	turbidity	turbidity s.e.	t e m p e r a t e	temperature se.
year	julian date								
76	182	239489.29	25129.27	61435.71	36575.02	2.33	0.26	16.94	0.95
76	182	239489.29	25129.27	61435.71	36575.02	2.33	0.26	16.94	0.95
77	177	93489.29	21219.21	0.00	0.(M	4.96	0. 28	19.21	0.57
78	177	199139.29	21448.38	142.86	524.53	2.37	0.36	17.62	0.91
79	142	210182.14	40131.81	15432.14	21512.75	2.04	0,26	14.50	0.s5
79	178	126553.57	31240.30	0.00	0.00	3.24	0.35	18.93	1.29
79	178	126.553 .57	312.$0.30	0.00	0.00	3.24	0.35	18.93	1.29
79	178	126553.5	31240.30	0.00	0.00	3.24	0.35	I S.93	1.29
80	177	1-9220.00	33447.85	1257.14	4'89,84	2.61	0.41	17.84	1.14
81	174	~1567?8,5	47662.52	31 253.57	46843.84	2.46	0.37	15.95	0.74
81	137	323146.43	80225.s2	14(X314.29	106622.02	2.54	0.39	13.19	0.S6
82	166	375535 .-1	44052.23	216.546.43	61516.07	1.78	0.50	15.67	0.75
82	137	342917.86	32356.43	1565%.43	31370.53	2.15	0.31	12.60	0.94
83	143	332089.29	49072.47	135685.71	5-$306.81	1.95	0.39	15.28	0.86
83	172	208635 .-1	19974.71	1S82.14	7443.12	2.2	0.-1o	17.18	0.81
84	164	325746.43	53853.34	144092.86	.$9355 .29	1.90	0.34	[5.2s	1.13
84	164	325746.43	53853.34	144092.86	49355.29	1.90	0.34	15.28	1.13
84	164	325746.43	53853.34	144092.86	49355.29	1.90	0.34	15.28	1.13
85	161	156932.86	YW9258	0.00	0.00	2.S8	0.42	17.54	1.45
85	161	156932.86	2999258	0.00	0.00	2.88	0.42	1-.54	1.45
86	90	254493.s-	Y¯, 38	3660-.543	24606.53	2.06	0.29	8.67	0.63
86	162	176905.36	52637.56	7900.7 1	15306.46	2.07	0.39	17.24	1.13
87	124	219$0:.14	3:9'1.98	32883.57	31953.6S	2.99	0.34	12.62	1.06
87	124	219407.14	3'9:1.98	32883.57	31%3.68	2.99	0.34	12.62	1.06
87	124	21940-.14	37971.98	32883.57	31%3.68	2.99	0.34	12.62	1.06
87	124	219407.14	37971.98	32883.57	31953.68	2.99	0.34	12.62	1.06
87	123	220241.43	37157.24	32940.00	31894.80	3.00	0.32	I 2-54	1.08
87	123	220241.43	37157.24	32940.00	31894.80	3.00	0.32	12.54	1.0s
87	123	2202.$1.43	37157.24	32940.00	31894.80	3.00	0.32	12.54	1.08
87	146	158191.07	34618.27	275.36	1457.05	2.%	0.37	15.22	1.45
87	175	106301.43	16441.2s	0.00	0.00	3,48	0.46	19.44	0.69
88	169	12364.$.29	20933.15	0.00	0.00	3.55	0.29	18.75	0.79
89	179	110425.36	17688.%	0.00	0.00	3.55	0.42	18.31	0.10

bother method of covariate characterization entails summarizing the daily total outflow, spill, temperature, and turbidity by a linear regression over the 28 days, in the form of

$$rivercov_i = \alpha_i + \beta_i x$$

where:

$rivercov_i$ = the river covariate for Priest Rapids hatchery release i $(i = 1..33)$ in this analysis;

β_i = the slope, or rate of change of the river covariate over the 28 days after the day of Priest Rapids release i;

x = days O to *27* following the release from Priest Rapids; and

α_i = the intercept, or initial river covariate value at the time of Priest Rapids hatchery release i.

The intercept represents the initial conditions at time of release, and the slope estimates the rate of change of those conditions through the month (Appendix D contains plots of the resulting fits to the data and R^2's). One of the obstacles to this kind of analysis is the general problem of synchrony, applying information measured over a time period which may or may not apply to the event being investigated. This method seems to better represent the river conditions experienced by the Priest Rapids stock for their first month in the river, as all fish experienced the initial condition, and slope (average change from initial condition over the month following release) appears consistent for periods longer than the 28-day period. As such, the slope would be the same whether a week, month or longer time period was used. Intercept and slope were always used together to determine significance of a particular river condition in each model. The area beneath the fitted regression line for the 28 day period was calculated as follows:

$$area_i = \int_0^{27} (\beta_i \cdot x + \alpha_i) = \left(\frac{\beta_i \cdot x^2}{2} + \alpha_i \cdot x\right)\Bigg|_0^{27} = \left(\frac{\beta_i \cdot 27^2}{2} + \alpha_i \cdot 27\right) \quad . \qquad (equation\ )$$

This area was used in subsequent calculations to determine the correlation among independent and dependent variables.

Transportation. Estimates of fish guidance efficiency (FGE) were obtained from National Marine Fisheries Service reports (Krcma et al. 1985, Swan and Norman 1987, Brege et al. 1988, and McComas et al.. 1993) to determine the fraction of fish transported from McNary Dam. These reports summarized the results of experiments conducted at McNary Dam to determine the fraction of spring and fall chinook smelts that go through the turbines or through the bypass system and thus into barges for transport to below Bonneville Dam. In addition to passage through the turbines or through the bypass system, some smelts are spilled with water that is diverted over the spillways. The consensus opinion on the fraction of fish that migrate over the spillways is that it is directly related to the fraction of water that is spilled on a one-to-one basis.

The estimated proportions of CWT chinook released at Priest Rapids and transported from McNary (P_T) were obtained using the following formula:

$$P_T = \sum_{i=0}^{154} (pa_i) \text{ x } (1 - ps_i) \text{ x } (FGE)$$

where: pa_i = the probability of arrival at day i (i = O, 1, ... 154);

ps_i = the proportion of spill at day i;

FGE = *the* fish guidance efficiency, assumed to be a constant (FGE = 0.3); and

i = O corresponds to the release day for the CWT group.

The values of ps_i were calculated as the ratios between the average spill and outflow on day i. Data were obtained from the Pacific States Marine Fisheries Commission (PSMFC) database. The values of pa_i were estimated from the distribution of travel times to McNary Dam of (a) freeze-branded and (b) PIT-tagged chinook released at Priest Rapids. The travel times of freeze-branded chinook from 39 samples, spanning 10 years (Table 7, Appendix C), were used to build a distribution for pa. A histogram was built from the freeze-branded data for travel times ranging from O to 154 days. All samples from the same year were scaled to 1000 fish before pooling them into an average histogram for the year. The final overall histogram was then obtained by combining these histograms resealed to 1000 fish. An alternative distribution for pa was estimated using the only Priest Rapids' PIT-tag release of fall chinook salmon available [1]. Both pa distributions are shown in Figure 5. Estimates of the proportions of CWT chinook released at Priest Rapids and trans-

1. The group consisted of 482 smelt released from between 6/13/94 and 6/21/94.

ported from McNary (P_T) calculated using the values of pa_i based upon freeze-brand (P_{T_a}) and PIT-tag (P_{T_b}) samples and are displayed in Table 2. Because values of P_T and P_{T_b} were almost identical, P_{T_a} *was* used in subsequent regression analyses.

Figure 5: Distribution of *pa* for Priest Rapids chinook.

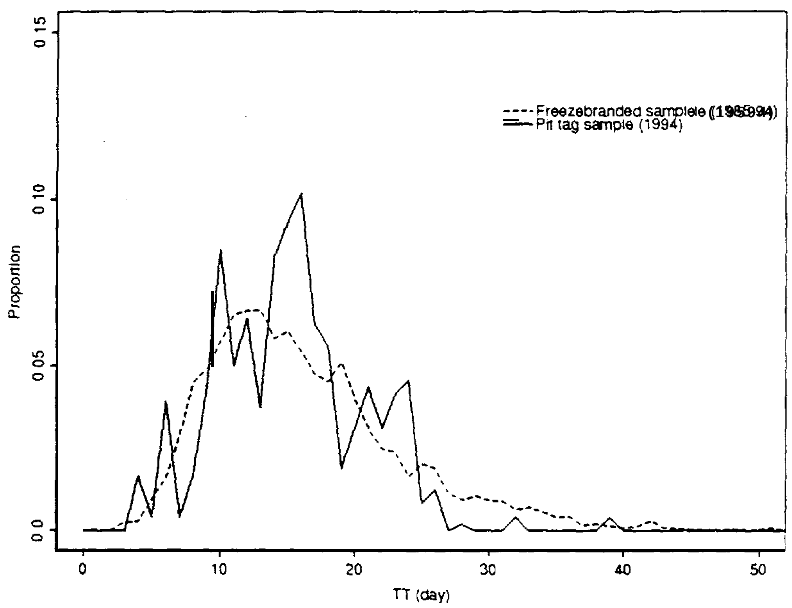


Table 2: Estimates of P_T based upon freeze-brand (P_{T_a}) and PIT-tag (P_{T_b}) samples.

CWT *Code*	Release Date	P_{T_a}	P_{T_b}	CWT *Code*	Release Date	P_{T_a}	P_{T_b}
131101	7/01/76	0.2239	0.2205	632860	6/13/84	0,1750	0.1726
131202	7/01/76	0.2239	0.2205	633221	6/1 1/85	0.3000	0.3000
631662	6/27/77	0.3000	0.3000	633222	6/1 1/85	0.3000	0.3000
631746	6/27/78	0.2997	0.2996	632330	4/01/86	0.2676	0.2624
631821	5/23/79	0.2922	0.2947	634102	6/12/86	0.2985	0.2985
631857	6/28/79	0.3000	0.3000	51915	5/05/87	0.2609	0.2670
631%8	6/28/79	0.3000	0.3000	51916	5/05/87	0.2609	0.2670
632017	6/28/79	0.3000	0.3000	51917	5/05/87	0.2609	0.2670
631948	6/26/80	0.2990	0.2997	51918	5/05/87	0.2609	0.2670
632155	6/'24/81	0.2823	0.2801	51919	5/04/87	0.2570	0.2606
632261	5/18/81	0.1631	0.1509	51920	5104187	0.2570	0.2606
632252	6/16/82	0.1224	0.1124	51921	5/04/87	0.2570	0.2606
632456	5/18/82	0.1645	0.1671	51922	5127187	0.2999	0.3000
632611	5124183	0.1868	0.1846	634128	6/25/87	0.3000	0.3000
632612	6/22/83	0.2987	0.2976	635226	6/18/88	0.3000	0.3000
632848	6/13/84	0.1750	0.1726	635249	6/29/89	0.3000	0.3000
632859	6/13/84	0.1750	0.1726				

Combining the probability of transportation with the estimated effect of transportation on the smelt survival, an multiplicative adjustment to smelt survival (S) for the Priest Rapids' release groups for the probability of transportation is then calculated by:

$$C_i = P_{T_i}\tau + (1 - P_{T_i}) \qquad \text{(equation 2)}$$

where: C_i = the (multiplicative) adjustment to a Priest Rapids release group's survival estimate;

P_{T_i} = *the* probability of transportation for Priest Rapids batch i;

τ = the multiplicative adjustment to survival of transported fish.

To estimate τ, a simplistic model of the expected number of fish recovered from a specific release can be written as:

$$E(n_T) = NSp\tau$$

where: n_T = total number of fish recaptured;

N = the total number of smelt released;

s = percent survival of the fish;

p = probability of recapture; and

τ = the effect of transportation on the smelt survival.

A ratio of recovered transported releases over control releases gives an estimate of τ. A transportation study conducted by the National Marine Fisheries Service on fall chinook salmon (Table C4, Appendix C) from 1986 to 1988 was analyzed to estimate the treatment-control ratio (TCR) at McNary Dam. Using GLM (generalized linear models) and assuming a binomial error structure, a log-link (Townsend and Skalski 1996) and a constant transportation-control ratio, the model describing the recovered proportion from a specific release is:

$$E(p_{ijk}) = a \cdot batch_i \cdot location_j \text{ “ } \tau_k$$

where: a = intercept;

p_{ijk} = proportion of recovered adult fall salmon for release batch i, location *j*, treatment *k;*

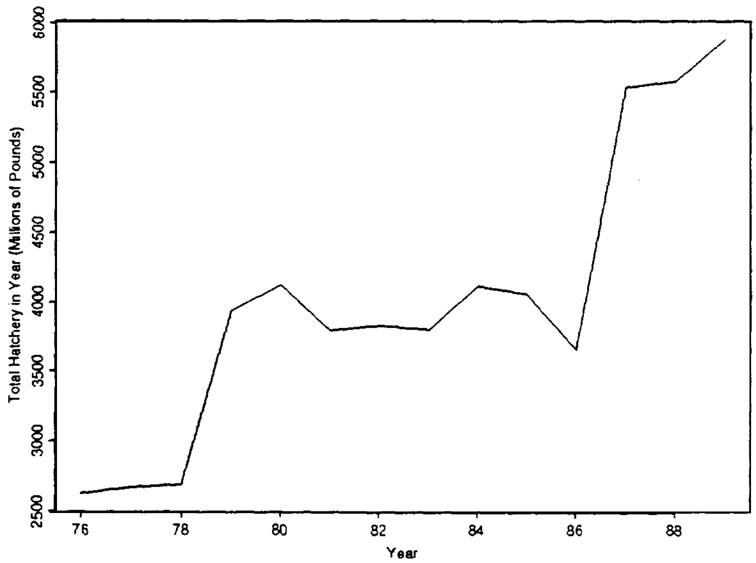
$batch_i$ = release covariate for group i (i = 1 to total number of releases for year);

$location_j$ = recovery covariate location j (*j* = dams, fisheries, hatcheries, or spawning grounds); and

τ_k = transportation-control ratio (k = control, treatment). $\tau = 1$ for control releases. A fixed TCR was used to keep the adjustment for the probability of transportation simple. The average TCR for the three years was determined to be 3.24.

Total Hatchery Contribution. The total weight of chinook, coho and steelhead salmon releases per season were calculated from the CWT database from the Pacific States Marine Fisheries Commision (Figure 6). We used the total weight because each species is released at a different size, and total biomass therefore was the best representation of total input to the river system. The data for chinook and coho salmon were complete, while the steelhead data was not--only the number of fish released were available for the steelhead production runs. To estimate the total weight of steelhead, the release size was multiplied by the average weight of a CWT tagged run for each brood year. The total did not include the production of wild salmon from Hanford Reach.

Figure 6:Total biomass of hatchery contributions to the Columbia River, 1976-89.



Virtual Population Analysis. Hilborn suggested using a Virtual Population Analysis (VPA) in Phase I (Hilborn et al., 1993a). To estimate the population size of each batch of salmon at age 2, a process recommended by the Pacific Salmon Commission (PSC) was used (Argue et al. 1983, Gulland 1965). First, the number of recovered salmon per age level (i) was determined (N_i) . Each age class was then divided by the estimated survival (D_i) (Table 3) for salmon from age 2 (A,) to age i. Summing over these results gives the total estimated number of salmon from that release batch that survived to age 2:

$$\hat{A}_2 = \sum_{i=2}^{7} \frac{N_i}{D_i}$$

where:

N_i = number of CWTs recovered at age i adjusted for sampling fraction,

D_i = survival to age_i, given that the fish survived to age 2.

An average VPA was used for downriver reference hatcheries that had more than one batch released in a given year. The VPA survival estimates to age 2 ($\hat{S}_2$) were based on the fraction

$$\hat{S}_2 = \frac{\hat{A}_2}{R}$$

where R is release size of the hatchery group.

Table 3: Values of survival rates from age 2 to year i, recommended by the Pacific Salmon Commission for virtual population analysis (vPA).

Age (i)	conditional survival (D_i)
2	1.00000
3	0.60000
4	0.42000
5	0.33600
6	0.30240
7[a]	0.21088

a. D_7 *was* extrapolated using a quadratic model. as only divisors for ages 1 through 6 were available from references.

2.2 Statistical Analysis

Starting with all hatchery fall chinook CWT-tagged stocks in the river basin, selection of potential reference stocks were based on the following criteria: 1) release dates: generally spring released stocks; 2) developmental stage: similar to Priest Rapids stock; and 3) production and/or index stocks (no experimental stocks). Cluster analysis on the prospective stocks, tabulated by recovery age and location was performed to find those stocks with the closest ocean catch distribution to the Priest Rapids stock. Using the "complete linkage"[1] clustering method in SPSS, the five reference stocks with the least cluster distance from the Priest Rapids stock were selected for further analysis. Chi-square statistics were calculated for varying levels of recovery-area size to obtain a statistical comparison between the five reference stocks and Priest Rapids stock. Counts for recovered CWT-tags, both adjusted and non-adjusted by the recovery fractions, were tabulated into cells representing various recovery area sizes, and then the differences in distribution (and thus, homogeneity) were estimated using a Pearson's chi-square test. Despite significant differences ($\alpha < 0.01$) in ocean recovery patterns between candidate reference stocks and the Priest Rapids stock, subsequent regression analyses were performed to investigate in-river survival relationships and the sensitivity of the analyses to the choice of reference stock.

Stepwise multiple regression analyses were used to describe survival relationships and test the significance of each river variable with each reference stock. Three approaches to the regression models were taken. The first approach was an extension of a model used by Hilborn et al. (1993) (Appendix A) that attempted to simultaneously use all five reference stocks as controls for variable ocean survival in conjunction with the Priest Rapids stock. The second approach used general linear models (GLM) to analyze CWT return numbers as functions of numbers released per batch, sampling fraction, and in-river conditions. These analyses directly matched a downriver reference stock with the Priest Rapids stock to control for ocean effects. A separate analysis was performed, corresponding to each of the reference stocks used. The third approach was based on the use of virtual population analyses (VPA) estimates of survival of hatchery stocks to age 2. As with the previous analysis, a downriver reference stock was matched with the Priest Rapids stock

1. Also known as the "farthest neighbor" clustering method.

to control for ocean survival. Again, five separate analyses were conducted using each reference stock matched one-to-one with the Priest Rapids stock. Interaction terms were not included here, due to the sheer number of models which were explored--with six explanatory variables, there are 720 combinations, and with five reference hatcheries, that increases the analysis to.3600 models. Finally, there were six different approaches (with and without adjustment for the probability of transportation), for a total 21,600 models to analyze using just main effects. Clearly, there is a lot of unexplored territory here and opportunity for uncontrolled type I error rates.

A new aspect of this analysis was an attempt to adjust CWT recovery data for the effects of smelt transportation at McNary Dam. A model-based adjustment for transportation was included in the regression models analyzed. As such, six variations on the multiple regression analyses were investigated as part of this report. Consistent results between the analyses would add credence and robustness to any conclusions reached.

2.2.1 Response Model for CWT Analysis Used by Hilborn et al. (1993a,b)

The first general approach to the CWT analysis was to use all five reference hatcheries simultaneously to offset the ocean survival and harvest rates, as no reference hatchery releases displayed similar ocean distribution. An indicator variable was included in the regression analysis to account for the difference between reference hatcheries. An indicator variable for year of release was also included to reflect differences from year-to-year. The annual river conditions were characterized as the daily average over a period of 28 days beginning the day of each Priest Rapid's release. Reference hatcheries had no river conditions associated with their release, so were assigned the grand mean over years for each river condition. The annual deviation from the grand mean of each river covariate was then calculated and used in the regression. The deviation from the grand mean for river conditions experienced by each reference hatchery batch was set to zero.

However, the value of zero for the river covariate deviations for the reference-stocks is a misrepresentation. In actuality, the appropriate designation for the reference conditions is as missing values because river conditions were nonexistent at those sites. Treating the missing values as zeros is inappropriate and can bias the regression results in a number of undesirable ways. This model is included for comparison of results between this and the earlier Hilborn et al. (1993) report and contrast with other model results.

The log-linear regression model used in this analysis can be expressed as:

$$\log\left(\frac{obsreturns_{ij}}{R_{ij}}\right) = \beta_1(relyr_j) + \beta_2(hatchery) + \underset{\sim}{x}'\underset{\sim}{\beta} \qquad \text{(model 1)}$$

where:

$\underset{\sim}{\beta}$ = vector of fitted regression coefficients;

x = the vector of covariates added to the model.

$obsreturns_{ij}$ = the expanded number of observed returns for the ith batch and the jth year.;

R_{ij} = the total number of salmon released for the ith batch and the jth year;

$relyr_j$ = indicator variable for the@ release year ($0 = 1976$); and

$hatchery$ = indicator variable for reference hatchery (0 = *Priest Rapids*).

2.2.2 Response Model for CWT Reanalysis Used by Hilborn et al. (1993 a,b), Adjusted for Transportation

With transportation of fish from McNary Dam also occurring during the time period used in this study, an adjustment for the probability of transportation was needed. The expected number of Priest Rapids hatchery CWT-tags recovered under a transportation regime can be expressed as the log-linear regression model:

$$\log\left(\frac{obsreturns_{ij}}{R_{ij}}\right) = \log(p_{Tij}\tau + (1 - p_{Tij})) + \beta_1(relyr_j) + \beta_2(hatchery) + \underset{\sim}{x}'\beta \qquad \text{(model 2)}$$

where:

p_{Tij} = the probability of transportation for the ith year, the jth batch of Priest Rapids stock. The total adjustment is referred to as C_{ij} as defined in Eq. 2, page 15, where $C_{ij} = [p_{Tij}\tau + (1 - p_{Tij})]$. For reference hatcheries, log(C) = O .

2.2.3 Response Model for Analysis of CWT Observed Counts, Not Adjusted for Transportation

This approach used a log-linear regression to compare the Priest Rapids stock to each of the downriver stocks separately. The response model was based on the expected value of observed CWT recovery numbers at Priest Rapids and reference stocks where:

$$E(obspr_{ij}) = R_{Pij} \cdot f_{Pij} \cdot (oceansurv) \cdot (harvrate) \cdot (rivsurv)$$

and

$$E(obsref_i) = R_{Ri} \cdot f_{Ri} \cdot (oceansurv) \cdot (harvrate)$$

where:

$obspr_{ij}$ = observed CWT count for the Priest Rapids hatchery stock for the jth batch in the ith year (i = 1976, ..., 1989);

$obsref_i$ = total observed CWT count for the reference group released in the ith year;

$oceansurv$ = ocean survival rate;

$harvrate$ = harvest rate;

$rivsurv$ = in-river survival rate;

R_{Pij} = total number of fish released for Priest Rapids for the ith year, the jth batch;

R_{Rij} = total number of fish released for reference stock for the ith year;

f_{Pij} = sampling fraction for Priest Rapids stock for the jth batch in the ith year (this was calculated as the reciprocal of the expansion factor reported by the PSC);

f_{Ri} = sampling fraction for the reference stock for the ith year,

The ratio of the observed counts from Priest Rapids and a reference hatchery stock would have the approximate (to the first term in a Taylor series expansion) expected value:

$$E\left[\frac{obspr_{ij}}{obsref_i}\right] = \frac{R_{pij} \cdot f_{pij}}{R_{Ri} \cdot f_{Ri}} \cdot (rivsurv) \qquad \text{(equation 3)}$$

and as such, the log-transformation of the expected value is:

$$\log E\left[\frac{obspr_{ij}}{obsref_i}\right] = \left(log\left(\frac{R_{Pij} \cdot f_{Pij}}{R_{Ri} \cdot f_{Ri}}\right)\right) + \underset{\sim}{x}'\underset{\sim}{\beta} \qquad \text{(model 3)}$$

where

$\log \frac{R_{Pij} f_{Pij}}{(R_{Ri} f_{Ri})}$ = offset term in general linear model (GLM) analysis;

$\underset{\sim}{\beta}$ = the vector of fitted regression coefficients; and

$\underset{\sim}{x}$ = the vector of covariates added to the model to describe river survival.

Multiple regression analysis was used to explore possible factors influencing in-river survival. The best single-variable model was determined first, then other independent variables are added to see if they captured any further information. This forward step-wise procedure continued until no further information was gained by adding additional variables to the model.

2.2.4 Response Model for Analysis of CWT Observed Counts, Adjusted for Transportation

Adjusting for the probability of transportation of some of the Priest Rapids' hatchery releases, the expected number of Priest Rapids hatchery CWT-tags recovered under a transportation regime can be expressed as:

$$E(obspr_{ij}) = R_{Pij} \cdot f_{Pij} \cdot (oceansurv) \cdot (harvrate) \cdot (rivsurv) \cdot (p_{Tij}\tau + (1 - p_{Tij}))$$

Denoting $[p_{Tij}\tau + (1 - p_{Tij})] = C_{ij}$ (Eq. 2, page 15), then the expected value of the ratio of recovery numbers at Priest Rapids to the reference stock (to the first term of a Taylor series expansion) can be written as:

$$E\left[\frac{obspr_{ij}}{obsref_i}\right] = \frac{R_{Pij} \cdot f_{Pij} \cdot C_{ij}}{R_{Ri} \cdot f_{Ri}} \cdot (rivsurv) \qquad \text{(equation 4)}$$

where:

p_{Tij} = probability of transportation of Priest Rapids hatchery fish at McNary Dam for the *i*th year, the *j*th batch; and

τ = the transportation-control ratio for these analyses set at τ = 3.24.

The log-linear regression with the adjustment for the probability of transportation can be expressed in the form:

$$\log E\left[\frac{obspr_{ij}}{obsref_i}\right] = \left(log\left(\frac{R_{Pij} \cdot f_{Pij} \cdot C_{ij}}{R_{Ri} \cdot f_{Ri}}\right)\right) + \underset{\sim}{x}'\underset{\sim}{\beta} \qquad \text{(model 4)}$$

where $\log\left(\frac{R_{Pij} f_{Pij} C_{ij}}{R_{Ri} f_{Ri}}\right)$ was treated as an offset in the GLM analysis.

2.2.5 Response Model for VPA Estimates, Not Adjusted for Transportation

VPA estimates were used as the response survival ratios, with a log-linear regression to compare the Priest Rapids stock to each of the reference stocks separately. The response model was based on the expected value of the VPA survival estimates to age 2 where:

$$E(\hat{S}_{Pr_{ij}}) = (oceansurv)\,(harvrate) \cdot (rivsurv)$$

and

$$E(\hat{S}_{Ref}) = (oceansurv) \cdot (harvrate)$$

where:

$\hat{S}_{Pr_{ij}}$ = VPA survival estimate for the Priest Rapids hatchery stock at age 2 for the *j*th batch in the *i*th year (*i* = 1976, ... 1989);

$E(\hat{S}_{Ref_i})$ = VPA survival estimate for the reference group at age 2 for the *ith year;*

oceansurv = *ocean* survival rate;

harvrate = harvest probability;

rivsurv = in-river survival rate.

The ratio of the age 2 survival rates from Priest Rapids ($\hat{S}_{Pr_{ij}}$) and a reference hatchery stock ($\hat{S}_{Ref_i}$) would have the expected value (to the first term in a Taylor series expansion) of

$$E\left[\frac{\hat{S}_{Pr_{ij}}}{\hat{S}_{Ref_i}}\right] = rivsurv$$

and as such, the log-linear regression model for survival would be of the form:

$$\log E\left[\frac{\hat{S}_{Pr_{ij}}}{\hat{S}_{Ref_i}}\right] = \underset{\sim}{x}'\underset{\sim}{\beta} \qquad \text{(model 5)}$$

where:

β = the vector of fitted regression coefficients; and

x = the vector of covariates added to the model.

2.2.6 Response Model for VPA Estimates. Adjusted for Transportation

The adjustment for the probability of transportation was again included in this model before subsequent regression analyses examined the in-river survival relationship. The expected survival of Priest Rapids hatchery releases can be expressed as:

$$E(\hat{S}_{Pr_{ij}}) = (oceansurv)\cdot(harvrate)\cdot(rivsurv)\cdot(P_{T_{ij}}\tau + (1 - p_{T_{ij}}))$$

where:

$\hat{S}_{Pr_{ij}}$ = VPA estimate of survival for the Priest Rapids hatchery stock at age 2 for the *j*th batch in the *i*th year (i = 1976, ..., 1989);

$\hat{S}_{Ref_i}$ = VPA estimate of survival for the reference group at age 2 for the ith year;

oceansurv = ocean survival rate;

harvrate = harvest rate;

rivsurv = in-river survival rate;

$p_{T_{ij}}$ = the probability of transportation for the *i*th year, the *j*th batch;

τ = the transportation-control ratio (set at τ = 3.24).

Denoting $[p_{T_{ij}}\tau + (1 - p_{T_{ij}})] = C_{ij}$ (Eq. 2, page 15), then the expected value of the ratio of VPA survival estimates at Priest Rapids ($\hat{S}_{Pr_{ij}}$) to the reference stock ($\hat{S}_{Ref_i}$) (to the first term of a Taylor series expansion) can be written as:

$$E\left[\frac{\hat{S}_{Pr_{ij}}}{\hat{S}_{Ref_i}}\right] = C_{ij} \text{ “ } (rivsurv)$$

The log-linear regression with the adjustment for the probability of transportation can be expressed in the form:

$$\ln E\left[\frac{\hat{S}_{Pr_{ij}}}{\hat{S}_{Ref_i}}\right] = \ln(C_{ij}) + \underset{\sim}{x}'\underset{\sim}{\beta} \qquad \text{(model 6)}$$

where:

in (C_{ij}) = offset, the estimated adjustment for the probability of transportation for the ith year, the jth batch of Priest Rapids stock;

$\underset{\sim}{\beta}$ = the vector of fitted regression coefficients; and

x = the vector of covariates added to the model.

3. RESULTS

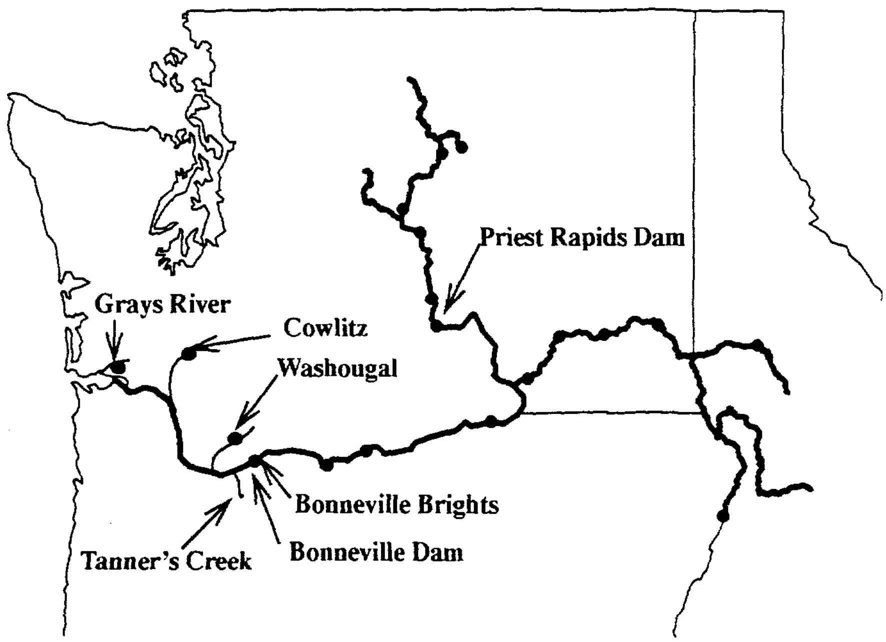
This section begins with the analysis to identify appropriate reference stocks, followed by a section on the correlation of the river covariates. Next are the analyses of the various response models for the CWT data. In all, six response models were investigated A summary of findings from the analyses of the various models is contained in the next section.

3.1 Reference Stocks

Because we attempted to analyze for the impact of river variables on survival, it was necessary to control for ocean conditions in the analysis of CWT data. One possible way to accomplish this was to locate stocks that were hatched or reared at or below Bonneville Dam that had similar ocean distributions to Priest Rapids stock. Because the precise ocean distribution of Columbia River stocks is unknown, ocean catch distributions were analyzed based on CWT catch data. The goal was to find stocks that could be used as reference stocks (not true controls).

3.1.1 Choice Of Reference Stocks

Figure 7: Map of hatcheries used in this analysis.



The choice of hatchery stocks to act as references in the analysis was begun using the cluster analysis from the draft of the previous report (Hilborn et al. 1993 b). Specifically, we started with the five fall, ocean-type hatchery stocks of chinook that cluster analysis indicated had the closest ocean catch distribution to the Priest Rapids stock (Table 5). There were usually several tag groups associated with each of the reference hatchery stocks, as well as numerous Priest Rapids hatchery stocks. Many of the tag groups were released at different times and were treated differently for various experimental purposes. We therefore selected a subset of the tag groups from each stock with the idea of reducing variability in the data set. The selected tag groups (Appendix C) were those that had been treated as normal production groups. The most up-to-date data (as of

November 1995) was obtained and analyzed the ocean catch distributions.

Table 4: List of potential reference hatcheries which were used in a cluster analysis against Priest Rapids. Hatcheries which consistently showed small distances from Priest Rapids were selected for this analysis (Table 5).

Stock	Brood year(s)	Stock	Brood year(s)	Stock	Brood year(s)
Abernathy	73-81.89	Kalama River	73-81.88	Sea resources	78-81
Big Creek	71,76-89	Klaskanine Hatchery	74,76-81,86-88	South Fork Klaskanine Pond	80-87
Big White Salmon	78	Klickitat Hatchery	75-81,86	south Santiam	77
Bonifer Pond	84	Lewis River	76-79,83,84	Speelyai	78
Bonneville Hatchery	76-89	Little White Salmon	76-81,83-88	Spring Creek	72-89
Cowlitz	77-88	Lower Granite Dam	72	Stayton Pond	76-89
Elokomin	73.76-81.85,88	Lyons Ferry	83-89	Toutle	71,72,76-78,87
Fallert Creek (lower Kalama)	71.72.77,79-81	oxbow	79-81	Turtle Ponds Creek	82-87
Grays River	74-82.84,85.88	Priest Rapids	75-88	Vanderveldt Ponds	80
Hagerman	78-81.83,84	Ringold Hatchery	71.75.77	Washougal River	73.76-87
Irrigon	84-89	Rock Creek Net Pens	85	Youngs Bay Net Pens	89

Table 5: Distance measures from cluster analysis, using Priest Rapids stock as the basis of comparison. Three types of distance measures were used: "Euclidean", "city block" and "Chebychev". Euclidean distance is the sum of the squared differences in values for each variable, city block is the sum of absolute differences in values for each variable; and Chebychev is the maximum absolute difference in values for any variable.

	Distance Measures		
Hatchery Stock	City Block	Chebychev	Euclidean
Bonneville	0.6070	0.1825	0.2300
Cowlitz	0.5370	0.1230	0.2103
Grays River	0.6229	0.1386	0.2486
Washougal	0.4315	0.0882	0.1521

3.1.2 Ocean Distribution Analysis

Tests for homogeneity of ocean distribution of stocks released 1976 to 1989 were conducted using the CWT ocean catch data, comparing each of the downriver stocks thought to be most like Priest Rapids stock (Table 5). The ocean catch data was considered at three levels of detail; (1) location within state/province, (2) grouped by state/province, and (3) grouped by state/ province and by catch year. Locations within state/province were the standardized locations for that state/province fisheries agency and used in the Pacific Salmon Commission's CWT database. Marine catches were grouped by region within state/province as the smallest area detail reported consistently in the CWT database (Table 6), then grouped by state/province (Table 7), as region within state/province had a high number of zero count cells in the distribution table. The third comparison tested the hypothesis that the ocean distribution was homogeneous by year and area of catch. Chi-square values ranged from (P $(\chi_5^2 > 563.39) \approx O)$ (Bonneville brights, grouped by state/province) to over ($P\ (xl_{1\,12} > 13008.64) \approx O)$ (Tanner Creek, grouped by state/province and by year). None of the potential reference groups were homogeneous (a « 0.01) in ocean recovery distribution with the Priest Rapids stock, but the Bonneville brights and Grays River stocks were the least unlike the Priest Rapids stock for all of the comparisons (Table 8). This non-homogeneity between the Priest Rapids stock and the candidate stocks mean that any analysis conducted using a treatment/reference relationship cannot attribute any differences in survival rates entirely to the conditions that the Priest Rapids stock experienced within the Columbia River and not to circumstances that occurred while the salmon were in the ocean.

Table 6: Number of CWT recapture records of fall chinook salmon with indicated reporting level for each hatchery (marine catches only), 1977-1994.

	Reporting Level Detail				
	state	region	area	location	sub-location
Bonneville Brights	3659	3472	3287	880	1906
Bonneville Tanner C.	3635	34%	3373	1002	1951
Cowlitz	1354	1330	1308	567	637
Grays River	687	666	648	198	357
Priest Rapids	4206	3906	3536	727	2123
Washougal	*2042*	1973	1880	477	1095

Table 7: Expanded CWT recapture counts of fall chinook salmon by state and hatchery, ‘ 1977-1994.

	AK	BC	WA	OR	CA	High Seas
Bonneville Brights	2760.71	7247.18	1390.10	578.41	63.18	32.23
Bonneville Tanner C.	1543.99	7435.71	2497.66	622.14	36.46	44.91
Cowlitz	257.60	1923.04	1512.75	632.09	6.61	26.94
Grays River	247.63	1323.53	569.03	136.61	22.78	14.19
Washougal	746.74	4282.69	1624.37	415.19	12.08	31.09
Priest Rapids	3939.98	8501.30	800.21	213.01	34.39	41.56

As a further demonstration of the difficulty in selecting an adequate downriver hatchery to be used as a reference stock for the Priest Rapids' releases, a test of homogeneity was done on just the Priest Rapids' ocean catch distribution (Table 9). Even the 9 replicate releases[1] in 1987 from Priest Rapids, $P(\chi_{120}^2 > 266.62) \approx 0$, did not have a homogeneous ocean distribution.

Table 8: Pearson's chi-square test for homogeneity in CWT marine recapture counts, 1977- 1994; Priest Rapids versus the indicated downriver hatchery. ($a \ll 0.001$ for all tests).

	Bonneville Brights		Cowlitz		Grays River		Tanner Creek		Washougal	
comparison	χ^2	Degrees of Freedom	χ^2	Degrees of Freedom	χ^2	Degrees of Freedom	χ^2	Degrees of Freedom	χ^2	Degrees of Freedom
Expanded catch counts using location within state/ province	1185.66	41	4978.61	41	2095.98	41	7806.84	45	3235.85	43
Expanded catch counts grouped by state/province	563.39	5	4244.57	5	1253.76	5	2127.41	5	2136.12	5
Expanded catch counts grouped by state/province and by year of catch	8346.43	112	10333.16	112	.5428 .11	112	13008.64	1112	6307.17	112

1. Table C 1 on page 142 has the breakdown of the counts data.

Table 9: Pearson's chi-square test for homogeneity in CWT marine recapture counts of Priest Rapids hatchery only, 1977 to 1994.

Comparison	score	Degrees of Freedom
Expanded catch counts using location within state/province	52779.37	39
Expanded catch counts using location within state/province and year of catch	6122.62	468
Expanded catch counts grouped by state/province	17440.61	4
Expanded catch counts grouped by state/province and year of catch	1841.12	48

3.2 Correlation of Independent Variables

Tables 10, 11, and 12 display the correlation coefficients calculated among the independent variables of flow, turbidity, temperature and spill. Tables 10 and 11 are for the method of linear regression characterizing each covariate, and Table 12 is the correlation determined between covariates characterized as monthly averages. F1OW and spill were highly correlated (r = 0.917), indicating that increased spill usually corresponded with increased flow. At the other extreme, spill and temperature had an inverse correlation (r = -0.346). An expanded correlation matrix was generated for all of the independent variables (Table 10). The most highly correlated variables were the intercept of spill and the intercept of flow *(r = 0.919)*, while the intercept of temperature had a low correlation with the intercept of spill (r= 0.016). Hatchery contribution was negatively correlated (r =-0.205) with flow. Temperature was the least correlated to the other river conditions, which may explain its inclusion in most "best" models.

Table 10: Correlation matrix for river conditions at McNary Dam for the 28-day period following fall chinook releases at Priest Rapids hatchery, 1976-1989. Correlations are calculated using the area under the regression line for flow, turbidity, temperature and spill (equation 1), the average spill ratio for the 28-day time period and the annual total contribution from hatcheries (lbs.).

Variable	Flow	Turbidity	Temperature	spill	Spill Ratio	Hatchery Contribution
Flow	1.000[a]	-0.786'	-0.565'	0.917[a]	0.938'	-0.205
Turbidity	-0.786'	1.000[a]	0.353[a]	-0.617'	-0.628[a]	0.315
Temperature	-0.565[a]	0.353[a]	1.000[a]	-0.346	-0.431'	-0.306
Spill	0.917[a]	-0.617'	-0.346	1.000[a]	0.987[a]	-0.201
Spill Ratio	0.938[a]	-0.628[a]	-0.431'	0.987'	1.000'	-0,180
Hatchery Contribution	-0.205	0.315	-0.306	-0.201	-0.180	1.000'

a. Correlation is significant (a< 0.05). with a Pearson's product moment correlation coefficient test.

Table 11: Correlation matrix for the individual elements of the river conditions at McNary Dam for the 28-day period following fall chinook releases at Priest Rapids hatchery, 1976-1989. Notation "a" indicates intercept term and "b" indicates slope term in regression of environmental variables against time.

Variable	Flow.a	Flow. b	Spill.a	Spill.b	Turb.a	Turb.b	Tempt.a	Tempt.b	Spill Ratio	H. Con.
Flow.a	1.000[a]	-0.498[a]	0.919[a]	-0.583[a]	-0.675'	-a.173	-0.547'	0.160	0.835[a]	-0.088
Flow.b	-0.498'	1.000[a]	-0.465[a]	0.869[a]	0.269	-0.085	0.150	-0.338	-O.(U(I	-0.225
Spill.a	0.919[a]	-0.465[a]	1.000[a]	0.656[8]	-0.s33'	-0.116	-0.33-	0.016	0.878[a]	-0.106
Spill.b	-0.583[a]	0.869[a]	0.656'	1.000[a]	0.296	-0.095	0.1-1	-0.115	-0.236	-0.098
Turb.a	-0.675"	0.269	-0.533[a]	0.296	1.000[a]	-0.364'	().295	-0.420[a]	-0.508[3]	0.411[a]
Turb.b	-a 173	-0.085	-0.116	-0.095	-0.364[a]	1.000[a]	0.262	0.313	-0.220	-0.366
Tempt.a	-0.54-'	0.150	-0.337	0.171	0.295	0.262	1.000[a]	-0.215	-0.412[a]	-0.308
Tempt.b	0.160	-0.338	0.016	-0.115	-0.420[a]	0.313	-0.2 15	1.003[a]	-0.041	0.046
Spilt Ratio	0.835"	0.040	0.878[a]	-0.236	-0.508[a]	-0.220	-0.412'	-0.041	1.000[a]	-0.180
Hatchery Contribution	-0.088	-0.225	-0.106	-0.098	0.411[a]	-0.336	-0.308	0.046	-0.180	1.000[a]

a. Correlation is significant (a< 0.05), with a Pearson's product moment correlation coefficient test.

Table 12: Correlation matrix of average river covariates at McNary Dam for the 28-day period following fall chinook releases at Priest Rapids hatchery, 1976-1989. The Hilborn model uses the deviance from the grand mean to characterize a river covariate.

Variable	Flow	spill	Turbidity	Temperature (C)	spill Ratio	Hatchery Contribution
Flow	1 .0000[a]	0.9165[a]	-0.7860’	-0.5655’	0.9384’	-0.2046
Spill	0.9165’	1.0003’	-0.6167’	-0.3463	0.9871’	-0.2013
Turbidity	-0.7860[a]	-0.6167[a]	1.0000’	0.3530’	-0.6277’	0.3153
Temperature (C)	-0.5655[a]	-0.3463	0.3530’	1.0000’	-0.4305’	-03058
Spill Ratio	0.9384’	0.9871[a]	-0.6277’	-0.4305’	1.0000	-0.1795
Hatchet-j Contribution	-0.2046	-0.2013	0.3153	-0.3058	-0.1795	1.0000[a]

a. Correlation is significant (a < 0.05), with a Pearson’s product moment correlation coefficient test.

3.3 Fitted Response Models

Because all of the reference stocks had significantly different (a « 0.01) ocean distributions when compared with Priest Rapids stock, each reference stock was used to check for the sensitivity of the regression results to the selection of reference stock. Consistency of results across different response models and different reference stocks suggested relationships that might be considered meaningful.

3.3.1 Analysis of Model Used by Hilborn et al. (1993a. b), Not Adjusted for Transportation

Model (1) was originally presented in the first draft of the report (Appendix A) with the addition of the additional independent variables discussed above. Averages of flow, spill, turbidity, and temperature were considered. In addition, indicator variables for release year and hatchery were used instead of conducting independent analyses against each reference stock. The indicator variables for year ($P(F_{13,304} > 40.24) = 1.0x10'^{6}$) and hatchery $P(F_{5,312} > 9.07) = 4.61x10^{-08}$) were highly significant and were treated as the base model for further analysis ($P(F_{18,299} > 36.39) << 0.001$).

Each of the independent variables were tested against the base model with all but temperature showing significance (Tables 13 and 14). The base model with hatchery contribution was the most significant ($P(F_{1,298} > 20.23) = 9.86x$ 10-M)). The next most significant variable was flow ($P(F_{2,297} > 24.93) = 9.8$ lxIO^{-11})); with spill, turbidity and spill ratio close behind ($P(F_{2,297} >$. 24.73) = 1.16x10-10), $P(F_{2,297} > 24.74)$ = 1. 15x10-10), $P(F_{2,297} > 24.49) = 1.43x10^{-10}$)), respectively. The normalized residuals plot (Figure 8) for the best fitting model, *hatchery + release year + hatchery contribution +-flow,* show an approximately normal distribution of model error, with the vertical stratification due to the use of indicator variables in the model.

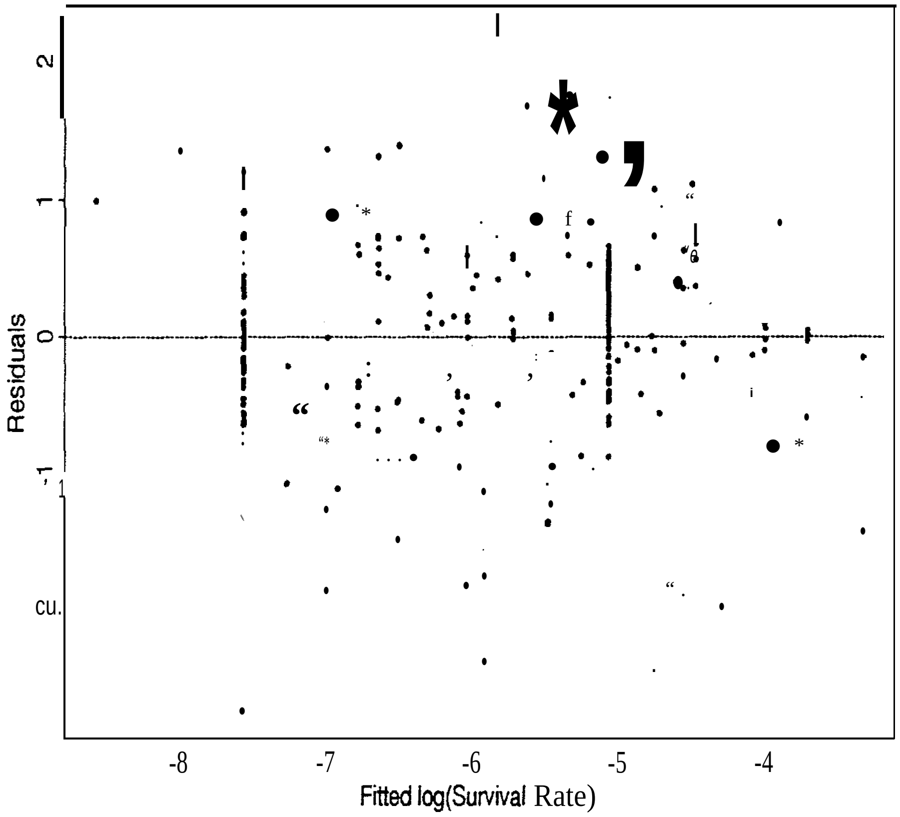
Table 13: Summary of R^2 for single river conditions for the Hilborn et al. (1993a,b) model (l), unadjusted for probability of transportation.

	river condition	p value	R^2
Base Model	hatchery	$4.61x10^{-08}$	0.6325
	release year	< LOX10-^{16}	0.6866
Base Model + 1 River Condition	hatchery contribution	$2.55x10^{-09}$	0.7219
	turbidity	$2.09x10^{-06}$	0.7094
	flow	9.86x10^{46}	0.7065
	-spill	$1.26x10^{-05}$	0.7061
	spill ratio	0.0001	0.7029
	temperature (C)	0.9559	0.6866

Table 14: Summary table for best fit models using Hilborn et al. (1993a,b) model (1), unadjusted for the probability of transportation. Standard errors of the coefficient estimation are in parenthesis.

Model	No. of Variables	Best Fitted Model	R^2	p
Base Model	13	y = -4.0077(0.5800) - 1.6190(0.7104)*relyr77 - 2.0483(0.7104)*relyr78 - 2.3652(0.6201)*relyr79 - 2.1576(0.6265)*relyr80 -1.6751(0.6098)*relyr81- 2.4988(0.6132)*relyr82 - 1.0859(0.6175)*relyr83 - 1.1957(0.6132)*relyr84 + 0.0329(0.6114)*relyr85 - 1.5164(0.6697)*relyr86 - 1.0846(0.5854)*relyr87 - 3.5365(0.5890)*relyr88 - 2.4512(0.6114)*relyr89	0.6325	$<1.0x10^{-16}$
	8	y = -4.0077(0.5400) - 1.3457(0.6729)*relyr77 -1.827 l(o.67w*@r78- 1.983 1(0.5s96) *relyr79 - 2.0100(0.5994)*relyr80 - 1.4442(0.5833)*relyr81- 2.3334(0.5860)*relyr82 - 1.1035(0.5906)*relyr83 - 1.2283(0.5858)*relyr84 + 0.0617(0.5876)*relyr85 - 1.2218(0.6351)*relyr86 - 0.7450(0.5641)*relyr87 - 3.1819(0.5700)*relyr88 - 2.2921(0.5871)*relyr89 + 0.6181(0.?1 1 I)* brights - 0.1800(0.2227)*cowlitz - 0.8827(0.2331)*grays - 0.3885(0.1600)*tanner + 0.1780(0.2438)*washougal	0.6866	$< 1.0X10^{-16}$
Base Model + hatchery contribution	9	y = -5.6640(0.5765) - 0.0230(0.6705)*relyr77 - 0.5473(0.6698)*relyr78 - 0.3543(0.6163)*relyr79 - 0.2249(0.6358)*relyr80 + ().3083(o.6ww*dyr81 - 0.5941(0.6212)*relyr82 + 0.6203(0.6239)*relyr83 + 0.5055(0.6206)*relyr84 + 1.7619(0.6196)*relyr85 + 0.2300(0.6442)*relyr86 + 0.2499(0.6235)*relyr87- 1.2532(0.6228)*relyr88 - 0.3572(0.6373)*relyr89 + 0.4959(0.2002)*brights - 0.2549(0.2105)*cowlitz - 0.8641(0.2200)*grays - 0.6546(0.1571)*tanner + 0.1501(0.2301)*washougal - 9.83x10^{-10}(1.60x10^{-10})*hatchery contribution	0.7219	$< 1.0x10^{-16}$
Base Model + hatchery contribution + flow	20	y = - 5.5855(0.5677) + 0.1359(0.6615)*relyr77 - 0.5492(0.6590)*relyr78 - 0.2984(0.6066)*relyr79 - 0.3042(0.6260)*relyr80 + 0.1721(0.6113)*relyr81 - 0.7831(0.6139)*relyr82 + 0.4849(0.6152)*relyr83 + 0.2913(0.6140)*relyr84 + 1.7111(0.6099)*relyr85 + 0.1870(0.6339)*relyr86 + 1.1429(0.6143)*relyr87 - 1.3508(0.6135)*relyr88 - 0.4369(0.6275)*relyr89 + 0.5386(0.1974)*brights - 0.2158(0.2075)*cowlitz - 0.9039(0.2168)*grays - 0.6292(0.1548)*tanner + 0.1537(0.2264)*washougal - 8.55x10^{-10}(1.62x10^{-10})*hatchery contribution + 5.93x10^{-06}(1.80x10^{-06})*flow	0.7317	<1.0X10-16

Figure 8: Normalized residual plots for Hilborn model, not adjusted for transportation



3.3.2 Analysis of Model Used by Hilborn et al. (1993a, b). Adjusted for Transportation

This analysis was identical to the one in Section 3.3.1, except that the VPA survival was adjusted for the probability that juvenile fish were transported via barge to below Bonneville Dam (Eq. 2). As above, we used the model presented in the first draft report (Hilborn et al. 1993b, Appendix A) and added additional river variables for the analysis of this model in this report. Indicator variables for release year ($P(F_{13,304} > 38.80) < 1.0\text{x}10\text{-}16$) and hatchery $P(F_{5,312} > 7.57) = 9.90\text{x}10^{-07}$) were highly significant and were considered as the base model for all further analysis ($P(F_{18,299}) > 34.74) < 1.0\text{x}10\text{-}16$)).

Each of the river covariates were tested against the base model with all but temperature showing significance (Tables 15 and 16). Hatchery contribution was the most significant ($P(F_{1,298}$ > 38.86) = 1.55x100)) of the additional single river variable models. After hatchery contribution was included in the model, spill was the most significant ($P(F_{2,297}$ > 27.82) = 9.74x 10-12)); with flow, turbidity and spill ratio close behind, $P(F_{2,297}$ > 27.63) = 9.90x10$^{-,z}$), $P(F_{2,297}$ > 26.55) = 2.46x10^{-1}1), $P(F_{2,297}$ >27.34) = 1.26x 10-12), respectively. At the next level of complexity, none of the additional independent variables were significant and no further analysis was conducted. The normalized residuals plot (Figure 9) for the best fitting model, *hatchery + release year + hatchery contribution + spill*, show an approximately normal distribution of model error, with the vertical stratification due to the use of indicator variables in the model.

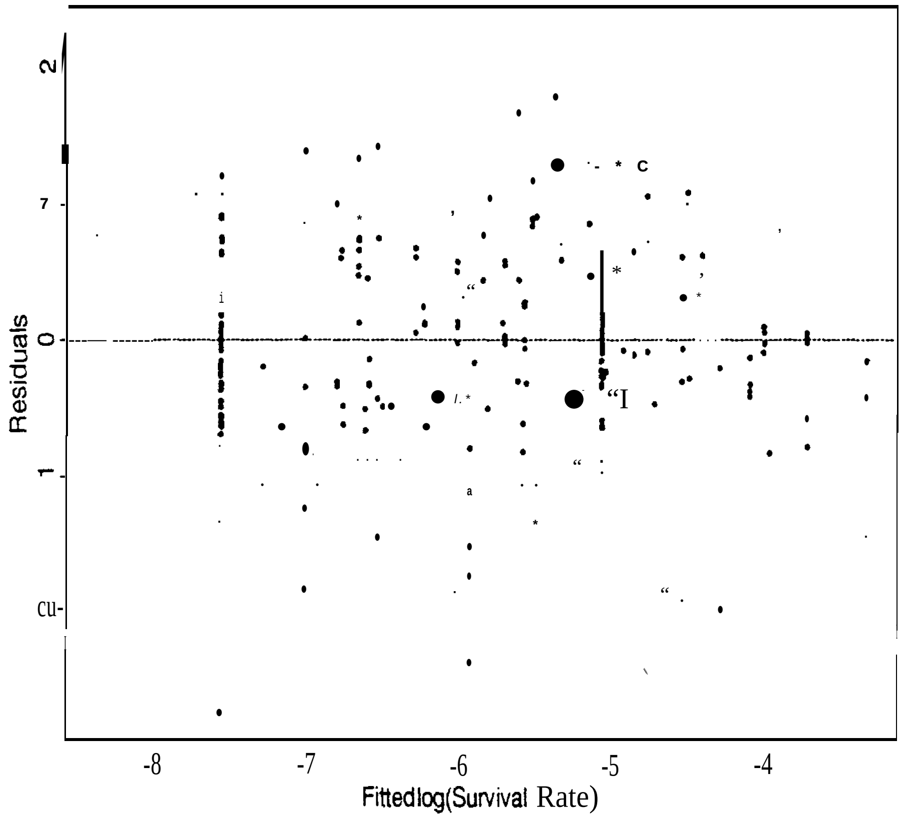
Table 15: Summary of R^2 for single river conditions for the Hilborn et al. (1993a,b) log-linear model (2), adjusted for probability of transportation.

	River Condition	P	R^2
Base Model	hatchery	$9.90X10^{47}$	0.1082
	release year	$< 1.0x10^{-16}$	0.6240
Base Model + *I* River Condition	hatchery contribution	1.55X 10-09	0.7138
	turbidity	$4.29x10^{-07}$	0.7031
	spill	$8.83x10^{-07}$	*0.7017*
	flow	8.86X 10-07	0.7017
	spill ratio	$6.05x10^{-06}$	0.6980
	temperature (C)	0.8742	0.6765

Table 16: Summary table for best fit models using log-linear response model (2), adjusted for the probability of transportation. Standard errors of the coefficient estimation are in parenthesis.

Model	No of Variables	Best Fitted Model	R^2	P
Base Model	13	$y = -4.4091_{(0.5821)} - 1.34613_{(0.7129)}*relyr77 - 1.7753_{(0.7129)}*relyr78 - 2.1102(0.62\sim)*ldyr79 - 1.7990_{(0.6287)}*relyr80 - 1.3147_{(0.6120)}*relyr81 - 2.1293_{(0.6154)}*relyr82 - 0.7417_{(0.6197)}*relyr83 - 0.8519_{(0.6154)}*relyr84 + 0.3772_{(0.6136)}*relyr85 - 1.2774_{(0.6722)}*relyr86 - 0.7228_{(0.5875)}*relyr87 - 3.1431_{(0.5911)}*relyr88 - 2.0784_{(0.6136)}*relyr89$	0.6240	$<1.0\times10^{-16}$
	18	$y = -4.4091_{(0.5444)} - 1.4138_{(0.6784)}*relyr77 - 1.8937_{(0.6801)}*relyr78 - 2.0532_{(0.5943)}*relyr79 - 2.0653_{(0.6042)}*relyr80 - 1.4882_{(0.5880)}*relyr81 - 2.3626_{(0.5904)}*relyr82 - 1.1498_{(0.5953)}*relyr83 - 1.2594_{(0.5905)}*relyr84 + 0.0051_{(0.5923)}*relyr85 - 1.2856_{(0.6402)}*relyr86 - 0.7985_{(0.5687)}*relyr87 - 3.2344_{(0.5747)}*relyr88 - 2.3459_{(0.5919)}*relyr89 + 1.0650_{(0.2128)}*brights + 0.2676_{(0.2245)}*cowlitz - 0.4242_{(0.2350)}*grays + 0.0647_{(0.1613)}*tanner + 0.6304_{(0.2457)}*washougal$	0.6765	$<1.0\times10^{-16}$
Base Model + hatchery contribution	19	$y = -6.0999_{(0.5802)} - 0.0635_{(0.6748)}*relyr77 - 0.5872_{(0.6741)}*relyr78 - 0.3904_{(0.6202)}*relyr79 - 0.2428_{(0.6399)}*relyr80 + 0.3009_{(0.6239)}*relyr81 - 0.5869_{(0.6252)}*relyr82 + 0.6099_{(0.6279)}*relyr83 + 0.5151_{(0.6246)}*relyr84 + 1.7407_{(0.6236)}*relyr85 + 0.1965_{(0.6483)}*relyr86 + 1.2380_{(0.6275)}*relyr87 - 1.2654_{(0.6268)}*relyr88 - 0.3705_{(0.6414)}*relyr89 + 0.9403_{(0.2015)}*brights + 0.1911_{(0.2119)}*cowlitz - 0.4052_{(0.2214)}*grays - 0.2071_{(0.1581)}*tanner + 0.6019_{(0.2316)}*washougal - 10.03\times10^{-10}_{(1.60\times10^{-10})}*hatchery\ contribution$	*0.7138*	$<1.0\times10^{-16}$
Base Model + hatchery **contribution** + spill	20	$y = -5.9816_{(0.5682)} - 0.0182_{(0.6600)}*relyr77 - 0.5458_{(0.6593)}*relyr78 - 0.3847_{(0.6065)}*relyr79 - 0.3520_{(0.6264)}*relyr80 + 0.1315(0.bI17)*relyr81 - 0.8637_{(0.6156)}*relyr82 + 0.4468_{(0.6103)}*relyr83 + 0.2206_{(0.6156)}*relyr84 + 1.6532_{(0.6095)}*relyr85 + 0.1869_{(0.6340)}*relyr86 + 1.0909_{(0.6148)}*relyr87 - 1.4112_{(0.6141)}*relyr88 - 0.5105(0,6\sim z)*relyr89 + 0.9947_{(0.1975)}*brights + 0.2333_{(0.2075)}*cowlitz - 0.4467_{(0.2168)}*grays - 0.1758_{(0.1548)}*tanner + 0.6061_{(0.2264)}*washougal - 8.55\times10^{-10}_{(1.62\times10^{-10})}*hatchery\ contribution + 8.74\times10^{-06}_{(2.28\times10^{-06})}*spill$	*0.7272*	$<1.0\times10^{-16}$

Figure 9: Normalized residual plots for Hilborn model, adjusted for transportation.



3.3.3 Analysis of CWT Observed Adult Counts. Not Adjusted for Transportation

The independent variables were tested in the model (3), one factor at a time for each reference stock (the slope and intercept were forced together into the model) for flow, spill, turbidity or temperature. The single-effect models (Tables 17 and 18) showed that flow, turbidity and spill ratio were significant with three of the reference stocks; while spill, temperature, and hatchery contribution were significant twice. None of the covariates were significant using the Cowlitz stock as the reference. The best models, based on the analysis of selected possible models for each of the four reference stock were: Grays River, temperature and hatchery contribution ($P(F_{3,14} > 7.09) = 0.0039$); Bonneville, turbidity and temperature ($P(F_{4,22} > 8.15) = 0.0003$); Washougal, flow and spill ratio ($P(F_{3,22} > 8.50) = 0.0006$); and Tanner Creek, spill ratio, turbidity and temperature ($P(F_{5,22} > 15.06) = 1.79x10W$). The normalized residuals plot (Figure 10) for the best fitting

Table 17: Summary of R^2 for single river conditions for each reference hatchery stock, using log -linear response model (3), unadjusted for probability of transportation.

River Conditions	Bonneville Brights	Cowlitz	Grays River	Tanner Creek	Washougal
Flow	0.2362*	0.1234	0.2694	0.3557*	0.3695"
Hatchery Contribution	0.3 146*	0.1077	0.0811	0.3465'	0.0455
Spill	0.2348"	0.0624	0.2181	0.4056*	0.1924
Spill Ratio	0.1825*	0.0550	0.2206*	0.3762'	0.1227
Temperature (C)	0.0514	0,0805	0.5465'	0.0253	0.2461*
Turbidity	0.4558*	0.1852	0.2525	0.3-433"	0.2535*

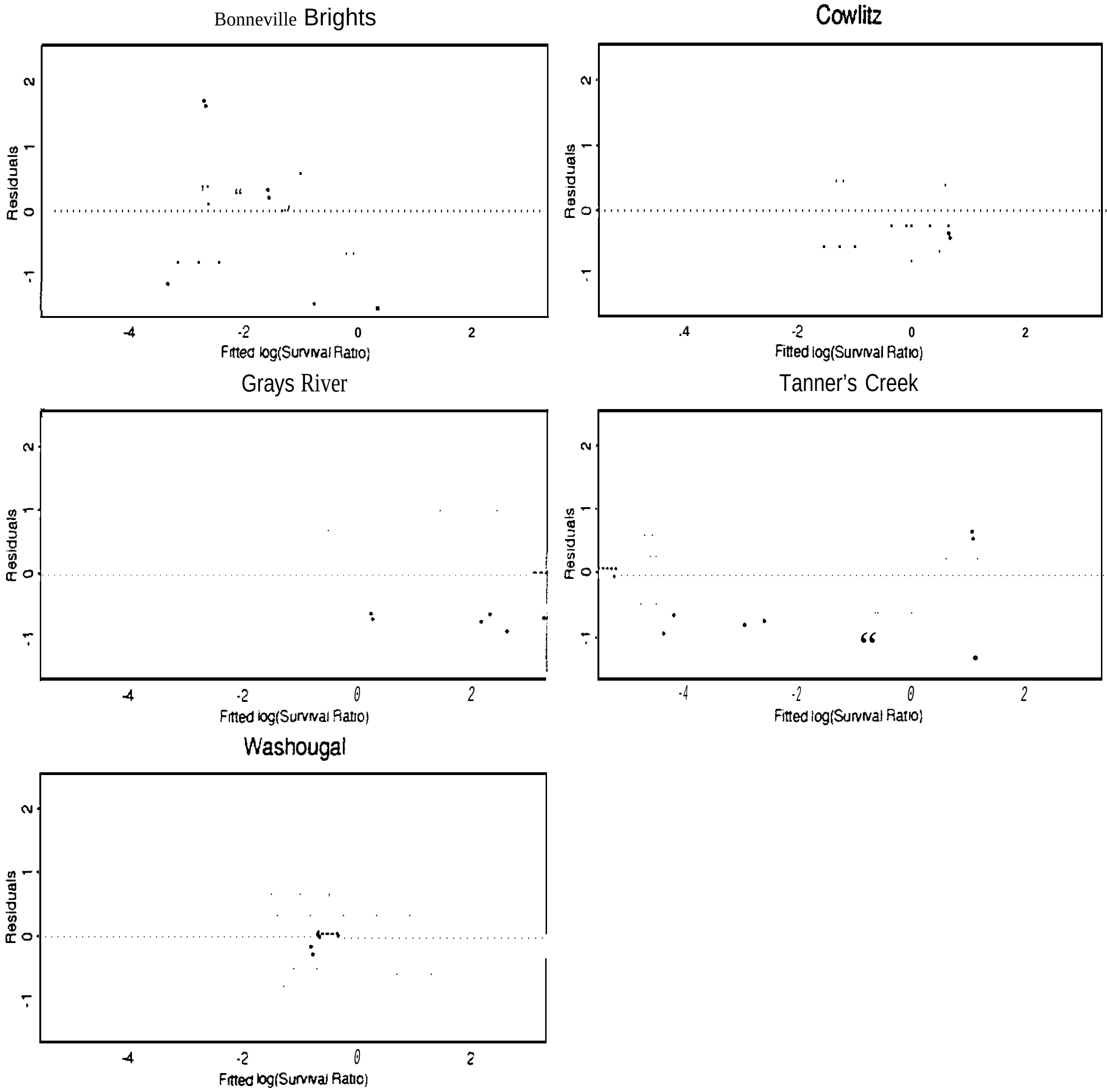
* indicates significance at $p < 0.05$

models show approximately normal distribution of model error in each comparison. The difference in groupings for each reference hatchery highlight the non-robustness of reference hatchery selection.

Table 18: Summary table for the best models for each reference stock using log-linear response model (3), unadjusted for the probability of transportation. Standard errors of the coefficient estimation are in parentheses.

Reference Hatchery	No. of Variables	Best Fitted Model	R^2	p
Bonneville Brights	2	y = 3. 1125(1.1746) - 1.6%8(0.4191)* turbidity.a - 2.0123 (14.5170) * turbidity.b	0,4498	0.0007
	4	y = 2.9043 (1.91 13) - 1.89240.4180) * turbidity.a - 1. 1545(20.7729) * turbidity.b + 0.1360(0.1 1s3) * tempt.a - 11.3393(7.2263) * tempt.b	0.5345	0.0003
Cowlitz	0	y = 0.7020(0.1107)	0.0000	1.23×10^{-06}
Grays River	2	y = 4.4725(1.1112) - 0.1267 (0.0678) * tempc.a - 13.6247(3.4638)* tempt.b	0.5-165	0.0027
Tamer Creek	1	y = -0.4967 (0.3209) + 5.2 190(1.31s0) * spill ratio	0.3762	0.0005
	3	y = -1.8797(1.4375) + 7.5598(1.6540) * spill ratio + 0.2095(0.4193) * turbidity.a + 55.043 1(1s.3932) * turbidity.b	0.6489	$I.16 \times 10^{45}$
	5	y = 1.2263(2.1045) + 6.0139(1.4805) * spill ratio - 0.4767 (0.4044) * turbidity.a + 50.9806(15.4785) * turbidity.b + 0.03 15(0.0920) * tempt.a - 14.0730(4.9549) * tempt.b	0.--39	0.7739
Washougal	2	y = -0.4806(0.3643) + 4.66×10^{-06} (1.47×10^{-06}) *flow.a + 1.44×10^{-04} (4.57×10^{-05}) *flow.b	0.3695	0.0050
	3	Y = -2.0170(0.6317) + 14.94×10^{-06} (3.87×10^{-06}) *flow.a + 2.92×10^{-04} (6.59x 10"05) *flow.b - 4.5242(1.6052) *spill ratio	0.5368	0.0006

Figure 10: Normalized residual plots for CWT observed adult counts, not adjusted for transportation



3.3.4 Analysis of CWT Observed Adult Counts, Adjusted for Transportation

The independent variables were tested in the model (4), one factor at a time for each reference stock. The single variable models (Tables 19 and 20) showed that spill ratio and turbidity were significant in four of the reference cases; flow, hatchery contribution and spill were significant three times; while temperature was significant only once. The best models, based on analysis of selected possible models for each of the five reference stocks were: Grays River, temperature ($P(F_{2,15} > 9.14) = 0.0024$); Bonneville, turbidity and temperature ($P(F_{4,22} > 8.57) = 0.0003$); Cowlitz, turbidity (($P(F_{2,23} > 2.24) = 0.0334$); Washougal, flow and spill ratio ($P(F_{3,22} > 10.24) =$ 0.0002); and Tanner Creek, spill ratio, turbidity and temperature ($P(F_{5,22} > 16.46) = 8.58\text{x}10^{-”T}$). The normalized residuals plot (Figure 11) for the best fitting models show approximately normal distribution of model error in each comparison. The difference in groupings for each reference hatchery highlight the non-robustness of reference hatchery selection.

Table 19: Summary of R^2 for single river conditions for each reference hatchery stock, using log-linear response model (4), adjusted for the probability of transportation.

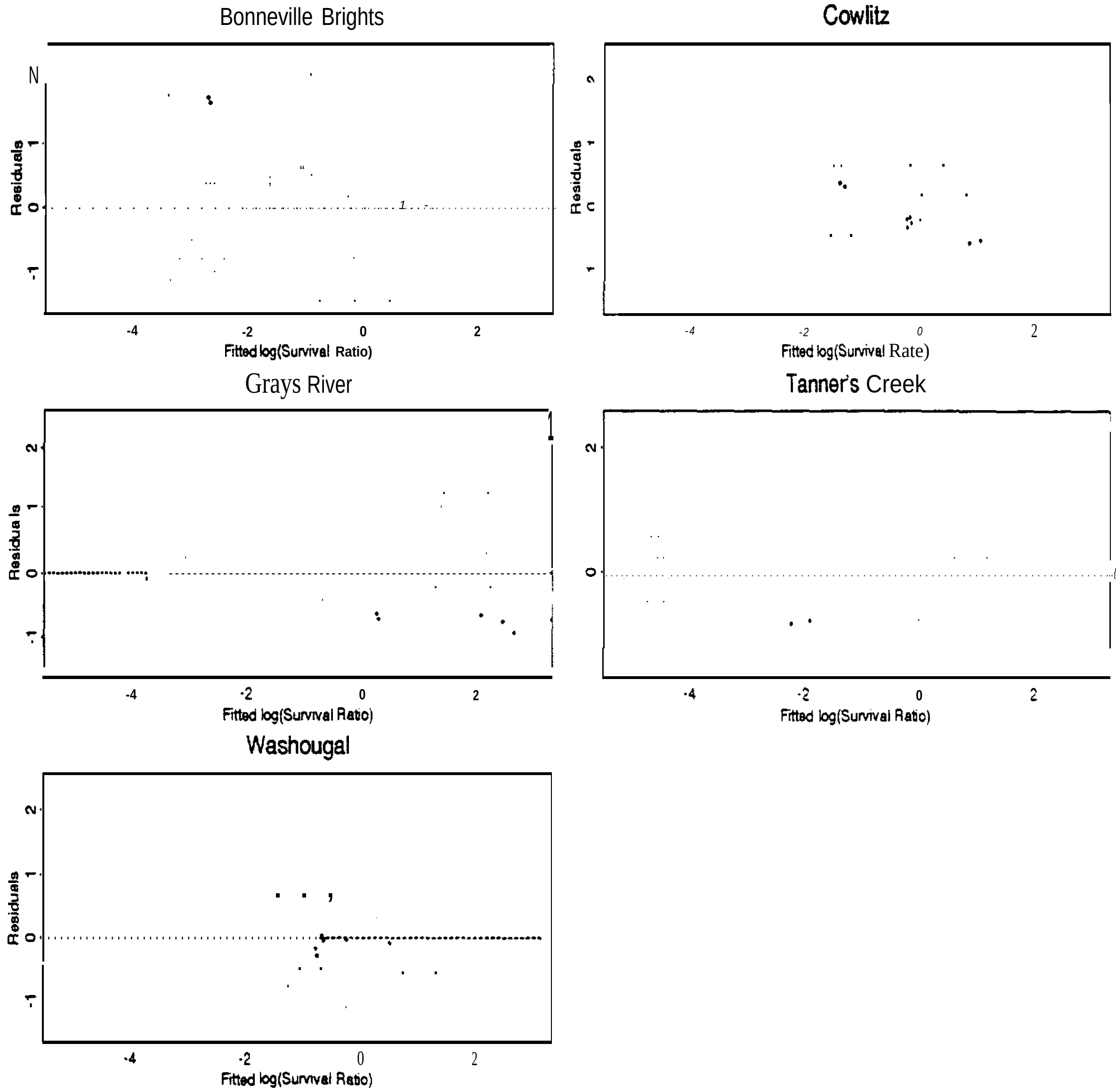
River Condition	Bonneville Brights	Cowlitz	Grays River	Tanner Creek	Washougal
Flow	0.2'761"	0.2216	0.3201	0.3916*	0.4634"
Hatchery Contribution	0.3211*	0.1307	0.0767	0.3405'	0.0518
Spill	0.2776*	0.1490	0.2835	0.4465'	0.2708*
Spill Ratio	0.2218*	0.1372	0.2863 *	0.4165'	0.2053*
Temperature (C)	0.0450	0.1003	0.5534"	0.0249	0.2604*
Turbidity	0.4744*	0.2559*	0.2898	0.3.$86"	0.3077*

* indicates significance at p <0.05

Table 20: Summary table for best models for each reference stock using log-linear response model (4), adjusted for the probability of transportation. Standard errors of the coefficient estimation are in parentheses.

Reference Hatchery	No. of Variables	Best Fitted Model	R^2	P
Bonneville Brights	2	y = 3.01220.1s51) - 1.8185 (0.4228) * turbidity.a - 5.6082(14.6468) * turbidity.b	0.4744	0.0004
	4	y = 2.7472(1.9328) - 2.0205 (0.4227) * turbidity.a + 5.3 198(21.0071) * turbidity.b + 0.1401(0.1196) * tempt.a - 11.1532(7.3078)* tempt.b	0.6092	0.0003
Cowlitz	2	y = 1.6984(0.5340) - 0.5480(0.1975) * turbidity.a - 7.4407(6.5788) * turbidity.b	0.2559	0.0334
Gray's River	2	y = 4.3101(1.1511) - 0.1437 (0.0703) * tempt.a - 14.071&33883)* tempt.b	0.5534	0.0024
Tanner Creek	1	y = -I .0189(03210)+ 5.6780(1.3181) * spill raao	0.4165	0.0002
	3	y = -2.4282(1.4363) + 80425(1.6527) * spill ratio+ 0.2172(0.4190) * turbidity.a + 55.2616 15.3809) * turbidity.b	0.6721	2.04×10^{-10}
	5	y = O.6O17C1OI9) + 6.5 107(1.4787)*spill ratio - 0.4709(0.4039) * turbidity.a +50.7643(15.4591) * turbidity.b + 0.0362(0.0919) * tempt.a - 13.9241 (4.9487) * tempc.b	0.7891	8.58×10^{-07}
Washougal	2	y = -1.1522(0.3532) + 5.70×10^{-06}(1.43×10^{-06}) * flow.a + 1.62×10^{-04}(4.43×10^{-05}) * flow.b	0.4634	0.0008
	3	y = -2.5155(0.6302) + 14.82×10^{-06}(3.86×10^{-06}) * flow.a + 2.93x1(T 04(6.57×10^{-05}) * flow.b - 4.01441.6oI~) * spill ratio	0.5826	0.01X)2

Figure 11 :Normalized residual plots for CWT observed adult counts, adjusted for transportation



3.3.5 Analysis of VPA Estimates, Not Adjusted for Transportation

The independent variables were tested in the model (5), one factor at a time, foIlowed by stepwise addition. Results (Tables 21 and 22) indicate that hatchery contribution was significant in three cases; while spill, turbidity, temperature, spill ratio, and flow were significant in two cases each. When the Cowlitz Hatchery stock was used as the reference, none of the independent variables were significant. The best models, from analysis of selected possible models (Table 22) for each reference stock (except Cowlitz), were: Grays River, temperature and hatchery contribution ($P(F_{3,14} > 5.67) = 0.0093$); Bonneville, hatchery contribution and spill ratio ($P(F_{2,24} > 10.61) = 0.0005$); Washougal, temperature and spill ratio ($P(F_{3,22} > 3.20) = 0.0432$); and Tanner Creek, hatchery contribution, spill ratio, and turbidity ($P(F_{4,23} > 15.85) =$ 2.31x1O*). Temperature and hatchery contribution were the most common variables included, though not always the most significant factor. The normalized residuals plot (Figure 12) for the best fitting models show approximately normal distribution of model error in each comparison. The best model using Cowlitz hatchery as a reference stock had only an intercept, thus the straight vertical line in the residuals plot. The difference in groupings for each reference hatchery highlight the non-robustness of reference hatchery selection.

Table 21: Summary R^2 for single river conditions for each reference hatchery stock, using log - linear response model (5) using VPA estimates, unadjusted for probability of transportation. Asterisk indicates factors significant at $P \leq 0.05$.

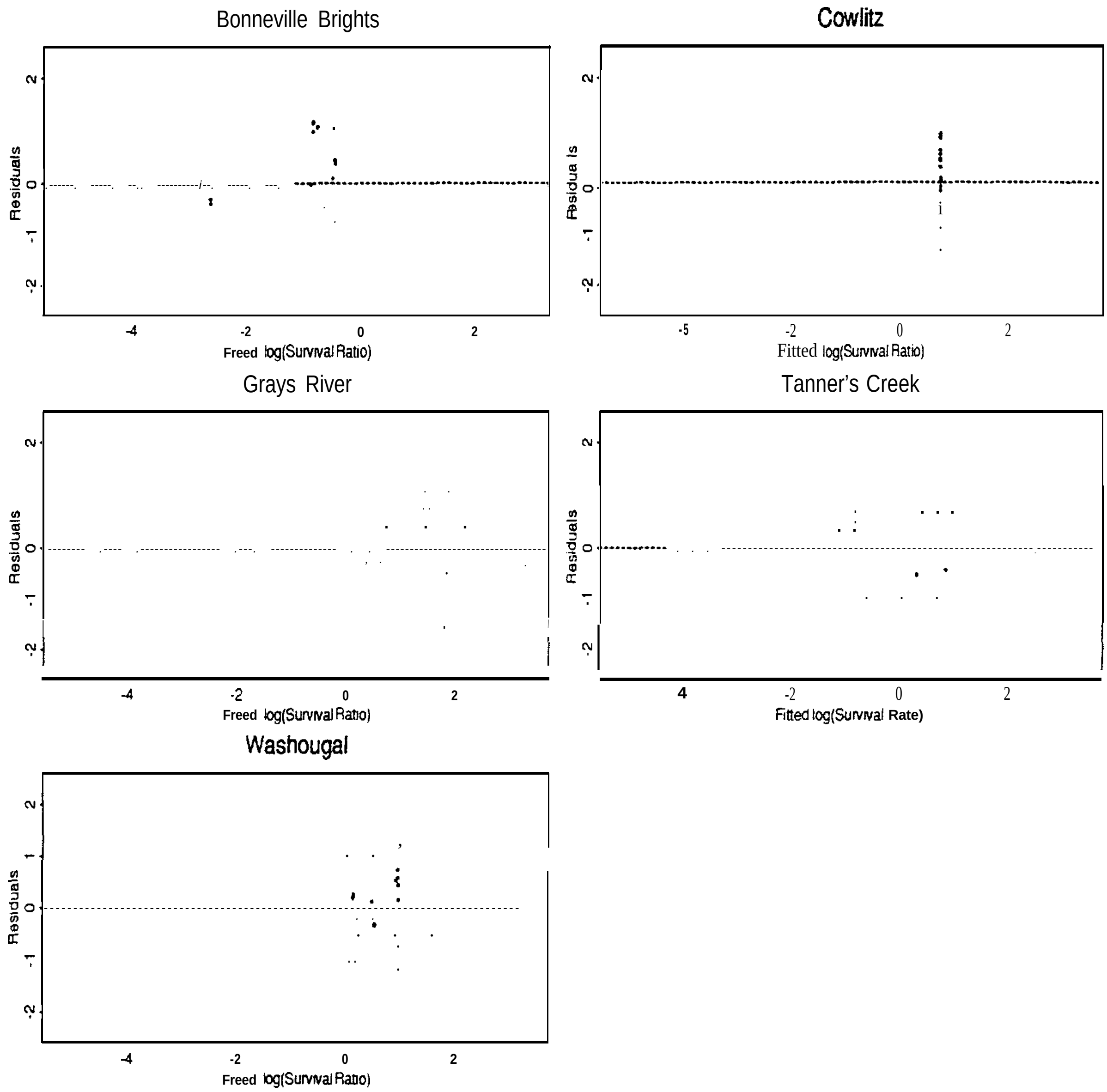
River Condition	Bonneville Brights	Cowlitz	Grays River	Tanner Creek	Washougal
Flow	0.1994	0.0507	0.1869	o.3i31 *	0.2278
Hatchery Contribution	0.4277"	0,0365	0.2198*	0.4016'	0.0237
spill	0.2370 *	0.0811	0.1850	0.4277*	0.1387
Spill Ratio	0.1677 *	0.0569	0.1682	0.3852"	0.1293
Temperature (C)	0.0714	0.0202	0.358.5"	0.0157	0.2738*
Turbidity	0.4256 *	0.0733	0.1:70	0.3655"	0.1581

* indicates significance at p <0.05

Table 22: Summary table for the best models for each reference stock using log-linear response model (5) based on VPA estimates, unadjusted for the probability of transportation. Standard errors of the coefficient estimation are in parentheses.

Reference Hatchery	No. of Variables	Best Fitted Model	R^2	p
Bonneville Brights	1	$y = 4.2971(1.ww - 1.25 \times 10^{-09}(2.88 \times 10^{-10})$ * hatchery contribution	0.4277	0.0002
Cowlitz	o	$y = 0,7573(0.1369)$	0.0000	9.48x10-W
Grays River	2	$y = 3.5152(1.3263) - 0.06960.0810)$* tempt.a - 11.6397(4.1343) * tempt.b	0.3585	0.0358
	3	$y = 6.0523\ (1.5548) - 0.0581(0.0705)$ * tempc.a 11.2638(3.5928) * tempt.b - $7.13 \times 10^{-10}(2.93 \times 10^{-10})$ * hatchery contribution	0.5487	0.0093
Tanner Creek	1	$y = 5.5777\ (1.2557) - 11.35 \times 10^{-10}(2.72 \times 10^{-10})$ * hatchery contribution	0.4016	0.0003
	2	$y = 3.9652(1.0698) - 9.29 \times 10^{-10}\ (2.21 \times 10^{-10})$*hatchery contribution + 4.2377(1.0423)*spill ratio	0.6398	2.86×10^{-06}
	4	$y = 1.4096(1.9381) - 5.31 \times 10^{-10}(2.44 \times 10^{-10})$*hatchery contribution+ 6.0783(1.6211)*spill ratio + 0.0587(0.3759)*turbidity.a + 37.2807(16.1833)*turbidity.b	0.7338	2.31x 10%
Washougal	2	$y = 3.0140(0.8743) -0.1503(0.0512)$*tempc.a - 3.4707(3.4022)*tempc.b	0.2738	0.0253

Figure 12: Normalized residual plots for VPA estimates of survival to age 2, not adjusted



for transportation.

3.3.6 Analysis of VPA Estimates, Adjusted for Transportation

In keeping with the previous analyses, each independent variable was tested in model (6) starting with a single-factor. Results (Tables 23 and 24) indicate that flow and spill ratio were significant with three of the reference stocks; while hatchery contribution, spill, turbidity and temperature were significant in two cases each. When the Cowlitz Hatchery stock was used as the reference, none of the independent variables were significant. The best models, from the analysis of selected possible models (Table 24) for each reference stock were: Grays River, temperature and hatchery contribution ($P(F_{3,14} > 5.60) = 0.0098$); Bonneville, hatchery contribution ($P(F_{1,25} > 19.05) = 0.0002$); Washougal, flow ($P(F_{2,23} > 5.05) = 0.0152$); and Tanner Creek, spill ratio, hatchery contribution and turbidity ($P(F_{4,23} > 17.48) = 1.03 \times 10^{-06}$). Hatchery contribution is the most common variable included, though not always the most significant factor. The normalized residuals plot (Figure 13) for the best fitting models show approximately normal distribution of model error in each comparison, The difference in groupings for each reference hatchery highlight the non-robustness of reference hatchery selection.

Table 23: Summary of R^2 for single river conditions for each reference hatchery stock, using log-linear response model (6) based on VPA estimates, adjusted for probability of transportation.

River Condition	Bonneville Brights	Cowlitz	Grays River	Tanner Creek	Washougal
Flow	0.0555*	0.1081	0.2438	0.3786*	0.3052"
Hatchery Contribution	0.4325”	0.0497	0.2072	0.3927*	0.0157
spill	0.2791‘	0.1542	0.2456	0.-$6s-”	0.2119
Spill Ratio	0.0053	0.1216	0.2302*	0.4253*	0.2036*
Temperature (C)	0.0592	0.0279	0.3689*	0.01285	0.2858*
Turbidity	0.46s2”	0.1111	0Z091	0.3692*	0.1983

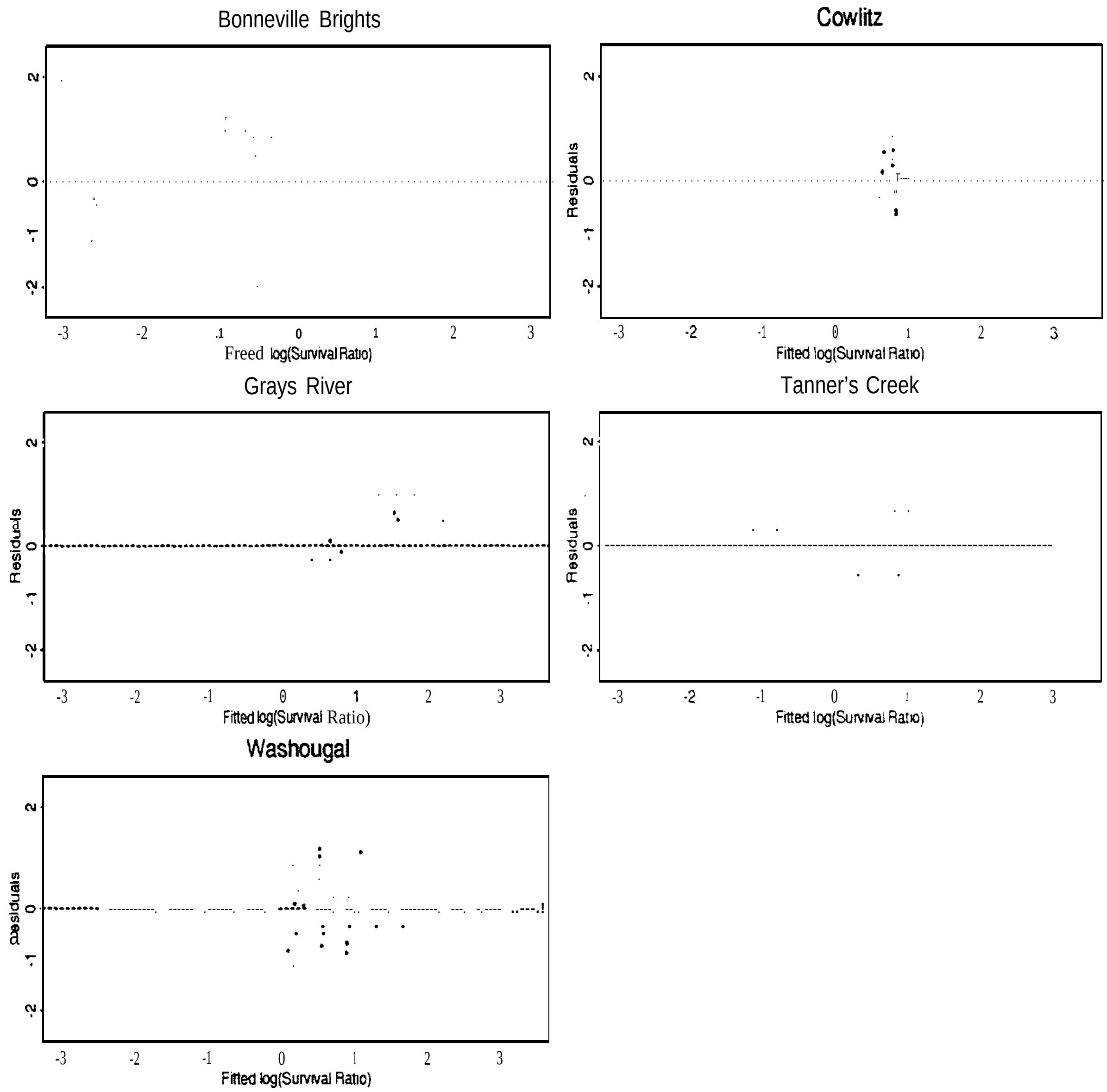
“ indicates significance at $p < 0.05$

Table 24: Summary table for best models for each reference stock using log (VPA ratios) adjusted for the probability of transportation as the response variable y = log (Priest Rapids VPA/ reference stock VPA). Standard errors of the coefficient estimation are in parenthesis.

Reference Hatchery	No. of Variables	Best Fitted Model	R^2	p
Bonneville Brights	1	y =4.0313(1.3782) - 1.29x 10^{-09} $_{(2.95\times10^{-10})}$ * hatchery contribution	0.4325	0.0002
Cowlitz	0	y = 0.3150(0.1423)	0	0.0362
Grays River	2	y = 3.3530(1.3672) - 0.0865 (0.0s35) * tempt.a - 12.0867(4.2617) * tempt.b	0.3689	0.0317
	3	y = 5.8938(1.6215) - 0.075 0(0.0735) * tempc.a - 11.7102(3.7472) * tempt.b -7. 14x10^{-1} *(3.06x 10-IIJ) * hatchery contribution	0.5455	0.0098
Tinner Creek	1	y = -0.9324(0.3166) + 5.7039(130031 * spill ratio	0.4253	0.0002
	2	y = 3.4641 (1.0672) + 4.6919(1.039s) * spill ratio - 9.33 x10^{-10} $_{(2.20\times10^{-10})}$ * hatchery contribution	0.6653	1.14×10^{-06}
	4	y = 0.89341.9343)+ 6.5456(1.6179) * spill ratio - 5.37x 10- ^{10} $_{(2.44\times10^{-10})}$ * hatchery contribution + 0.0649(0.3751)* turbidity.a + 37.3059(16.1516) * turbidity.b	0.7018	1.03×10^{-06}
Washougal	2	y = -0.9249(0.4483) - 5.41 x10^{-06} $_{(1.81\times10^{-06})}$ * flow.a - 13.46x10^{-05} $_{(5.63\times10^{-05})}$ * flow.b	0.3052	0.0152

Figure 13: Normalized residual plots for VPA estimates of survival to age 2, adjusted for transpor-

tation.



4. DISCUSSION

All of the river covariates used in this study were significant in some portion of the analysis. The variable that was most often significant across models (3-6) was temperature, followed by hatchery contribution, then spill ratio, turbidity and flow, in descending order. For the Hilborn et al. (1993) type models (l-2), hatchery contribution accounted for most of the variability followed by turbidity, then flow. It is interesting to note that hatchery contribution was consistently imp ortant in most of the models. Some of the differences between models (1-2) and (3-6) maybe due to the way in which the river variables were characterized. In the models (3-6), slope and intercepts for flow, temperature, and turbidity were treated as independent variables; while in the Hilborn et al. (1993) models (l-2), averages were used.

Best-fit response models did not change between analyses that adjusted and did not adjust for the probability of transportation at McNary Dam (Table 25) for most of the different reference hatchery stocks. This was not surprising, since the adjustment for transportation was nearly constant over the time period of this study. However, the best fit response model did change, whether CWT data were converted to VPA survival estimates or not. The Hilborn et al. (1993) models (l-2) also yielded different best-fit models than models (3-6). Furthermore, the resultant response model was quite sensitive to which reference stock was matched with the upstream Priest Rapids stock. No two reference stocks yielded the same choice of best explanatory variables. The purpose of repeating the analysis with each of the reference hatcheries was to determine robustness. Unfortunately, this was not the case, re-enforcing the fact that the lack of homogeneity in marine recoveries found between the Priest Rapids and the reference hatcheries would influence any analysis comparing survivals. These retrospective and correlative analyses can yield widely varying results dependent solely on choice of statistical analysis and reference hatchery. The wide ranging results depending on choice of reference stock invalidates the findings of the individual regression analyses. There is no basis to conclude the results from any one reference stock are any more reliable than another.

Table 25: The significant river covariates that enter into the "best" model for each type of response model and reference stock.

Hilborn et al. (1993) Models		
Reference Stocks	Model (1) VPA Ratio (unadjusted)[a]	Model (2) VPA Ratio (adjusted)[b]
All	hatchery contribution + flow	hatchery contribution + spill

Skalski/Townsend Response Model				
Reference Stocks	Model (3) Observed Count Ratio (unadjusted)[a]	Model (4) Observed Count Ratio (adjusted)[b]	Model (5) VPA Ratio (unadjusted)[a]	Model (6) VPA Ratio (adjusted)[b]
Grays River	temperature	temperature + hatchery contribution	temperature + hatchery contribution	temperature + hatchery contribution
Bonneville Brights	turbidity + temperature	turbidity + temperature	hatchery contribution	hatchery contribution
Cowlitz	none	turbidity	none	none
Washougal	flow + spill ratio	flow + spill ratio	temperature	flow
Tanner Creek	spill ratio + turbidity + temperature	spill ratio + turbidity + temperature	hatchery contribution + spill ratio + turbidity	spill ratio + hatchery contribution + turbidity

a. Priest Rapids adult survivals not adjusted for the probability of transportation
b. Priest Rapids adult survivals adjusted for the probability of transportation.

Despite initial hopes, the regression analyses conducted in the study indicated that the model results were highly dependent on the choice of reference stock. Rather than find the regression results robust to the choice of reference stock, the number and array of independent variables entering the regression models varied widely. Using Cowlitz Hatchery as the reference stock, none of the independent variables were found to be significantly correlated with estimated smelt survival. With the other reference stocks, the selection of individual variables also differed between stepwise regression models. With the other reference stocks, one to four independent variables entered the stepwise regression models. No convincing reoccurrence of independent variables suggested one or more key factors were predominantly related to smelt survival.

This analysis, rather than identifying potential key environmental factors influencing smelt survival and establishing working hypotheses on possible mechanisms for further testing, found *posthoc studies* using upstream-downstream pairing an unsuccessful avenue of investigation. This study had the choice of thirty-three reference stocks. Even with this large number of choices, the five best matched reference stocks had highly significant differences ($P \ll 0.001$) in ocean distribution compared to Priest Rapids, and yielded widely different conclusions. The conclusions from any one reference stock could have been badly misconstrued if sensitivity studies had not been conducted. The choice of reference stock is so influential on the regression results and so highly variable as to render the analyses unreliable. Consequently, our findings are not encouraging for other investigators planning similar correlative investigations.

Finding two stocks that show similar ocean distributions but differ in-river rearing environment appears a limitation of this paired-stock approach. The assumption of ocean mixing is needed because CWT data do not readily lend themselves to analyses that can separate out survival effects from harvest effort. Return rates on CWT releases are a composite of survival, harvest, and sampling effort. Without precise information on fishing effort to adjust the catch, the CWT data confounds changes in survival with differential fishing vulnerability. Hence, as long as ocean distributions differ, the potential exists for differential harvest confounding perceived changes in CWT return rates. The widely differing results we obtained with the reference stocks that had different ocean distributions suggest this is a problem.

The analysis suggests several possible directions for further research. This study used a correlative observational study to identify important smelt survival relationships. The many confounding and overlapping environmental factors inherently limit the success of this approach. Instead, an experimental approach to test working hypotheses concerning smelt survival would be preferable.

The proposed experiment could possibly involve rearing up-river brights in both upstream and downstream hatcheries simultaneously and/or doing the reverse with a tule stock. An obvious candidate stock is the Bonneville brights. They are reared at Bonneville Darn and are probably composed of many different upstream stocks. The Bonneville bright stock is sufficient y successful to occur in fairly large numbers; and given their possible origins and their current rearing location in a lower river hatchery, they would probably do well in both up-river and downriver settings. The next issue would be how to control the river variables. To be done successfully, the interaction of the river variables would need to be controlled in a way that would allow them to be sorted out.

The Columbia Basin fisheries community would need to have the conviction to replicate and manipulate river conditions over many years and wait even more years for adult fish to return. To resolve some of the difficulties in interpreting CWT returns, auxiliary information on fishing effort and fleet distributions would have to be collected over the years of the study. Onboard Global Positioning System (GPS) and PIT-tag scanning should be investigated to improve the quality of harvest data. These and other steps may be needed to unravel in-river survival relationships based on adult return information. This retrospective analysis of historical CWT data suggests existing databases and correlative investigations may shed little light on in-river survival relationships.

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Appendix A: Hilborn et al. (1993b) Report

Initial peer-reviewed manuscript entitled, "The relationship between river flow and survival for Columbia River chinook salmon," authored by R. Hilborn, R. Donnelly, M. Pascual, and C. Coronado-Hernandez (1993 b).

The relationship between river flow and survival for Columbia River chinook salmon

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Abstract

We explored the relationship between Columbia River flow, and survival from hatchery release to recovery of adults in catch and escapement for Columbia River chinook salmon. The only hatchery that was above the lower river darns and had a long time series of coded wire tag (CWT) release groups was the fall chinook stock at Priest Rapids hatchery. The survival as estimated by virtual population analysis (VPA) does show an increase with increasing flow. However, it is clear that major changes in survival at Priest Rapids hatchery were also seen in lower river hatcheries, and are presumably due to changes in general ocean condition. To correct for these ocean changes, we used lower river hatcheries as controls on ocean condition. The relationship between flow and survival when corrected for ocean condition shows a stronger correlation, which is highly significant. The slope indicates that an increase in flow of 100,000 cfs at McNary darn would result in 65% increase in survival of Priest Rapids hatchery fish.

We explored the sensitivity of these results to the choice of statistical models, and the inclusion of experimental CWT groups. All sensitivity tests we conducted indicated a si-mi.flea.nt relationship between flow and survival. The study does have a number of weaknesses, including the fact that only the Priest Rapids hatchery stock was available to test the relationship between flow and survival, and this stock passed only through the four lower river dams. No Snake River or upper Columbia hatchery stocks were available for testing. Further, there are a number of weaknesses in the use of the CWT data base, which include problems in recreational catch sampling, inter-dam loss of migrating adults, and escapement sampling methods.

Introduction

Columbia River salmon have been fished for perhaps thousands of years. With the arrival of western European settlers the magnitude of the exploitation increased dramatically. At its peak, the Columbia River salmon stocks produced catches of over 6 million fish from 5 species (Chapman 1986). The peak catches for each species occurred at different times over a period of about 30 years centered around 1900. Chapman (1986) estimated that total return to the Columbia River, catch and escapement, was in the neighborhood of 7.5 million fish. The five species of salmonids native to the Columbia River are chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), coho salmon (O. *kisutch*), and steelhead trout (*O. masu*). Chinook salmon are recognized as having two distinct life histories, ocean and stream. When discussing Columbia River chinook, fisheries managers commonly refer to three races based on time of the return migration: spring, summer, and fall. Spring chinook have a stream-type life history, fall chinook have an ocean-type history, and the summer stocks are a mixture of the two. After emergence, stream-type juveniles spend one year in fresh water, generally in a tributary stream, before migrating to sea, and are known as "yearlings". Ocean-type juveniles, termed "sub-yearlings", out migrate at the end of the first summer.

Beginning about the turn of the century, catches began to show a downward trend although the annual fluctuations continued. The adults that migrate into the river during the summer have suffered the most (Thompson 195 1), declining to very low numbers. recovering slightly in 1959 and then declining again (Chapman 1986). Most authorities (e.g. Laythe et al. 1948, NWPPC. 1986) have attributed the decline in chinook runs to a wide variety of causes including deforestation, farming, mining, pollution, over-fishing, unscreened water diversions and construction of dams - the last considered to be the major contributor. To overcome these problems, Laythe (1948) suggested a mitigation program in the lower river which included screening, water diversions, and habitat protection, as well as the construction of fish hatcheries. The hatcheries and lower-river efforts were never fully implemented and by the mid- 1970's the runs of chinook salmon to the mid-Columbia were at extremely low levels. The use of hatcheries to increase the runs had proved relatively unsuccessful.

Studies were initiated on the surviving chinook salmon stocks in the mid-Columbia River from Bonneville Dam to Grand Coolee Dam. Raymond (1969, 1979, 1988) studied the effect the dams were having on travel time of the out migrant smelts. Two major findings from his work were (i) wild stocks had better survival compared to hatchery stocks, and (ii) impoundment of water behind the dams slowed out migration and were thought to reduce survival. The direct effect of river discharge on downstream movement of salmon fry has been studied by a number of investigators (Irvine 1986; Giorgi et al. 1990: Raymond 1968; Park 1969; Stevenson and Olsen 1991) with varying results. Giorgi et al. (1990) investigated the relation of flow to travel time of sub-yearling chinook salmon and were unable to conclude that changes in flow *were* related to changes in travel time; however they did note that fish moving out in the early part of the summer had higher survival to adulthood compared with those that out migrated later. Raymond (1969) found that the John Day Reservoir increased the travel time of out migrant smelts-from 14 days to 22 days for that stretch of river. Stevenson and Olsen (199 1), experimenting with different flow regimes in John Day Reservoir, were unable to demonstrate a solid relationship between flow and travel time. Park (1969) concluded that, with the advent of dams, the peak flows were reduced, turbidity was decreased, predation and disease increased, and that "an almost continuously impounded river, with resultant trends toward wan-ring water and increased numbers of predators, and *other* complex changes in the environment, could eventually jeopardize the existence of the chinook salmon in the [mid] Columbia River."

There is little question that the downriver movement of the juvenile salmon has been slowed by the construction of dams (Raymond 1979; Ebel and Raymond 1976). For each darn constructed above Ice Harbor dam on the Snake River, the travel time was increased by about 50% or more (Ebel and Raymond 1976), or an average delay of 8 days per reservoir. Raymond found that migration rates for juveniles were on the order of 40 to 55 km/day for both free flowing and impounded stretches at moderate river flows (about 8,500 m^3/sec.), and in the range of 24 to 27 km/day at low flows (about 4250 m^3/sec.).

While the hypothesis that flow and travel time are inversely related is viewed as a basis for present river management, the situation is not as clear as might be hoped - apparently confused by confounding variables. For example, travel time is related to the condition of the juveniles at time of migration. Their physiological condition is related to water temperature which in turn is related to the time of year (Giorgi et al. 1988). The later in the year, the faster the juveniles appear to migrate (Chapman et al. 1991).

In an effort to shed light on a complex situation and to prevent continuing erosion of Columbia River salmon runs, Congress passed the Pacific Northwest Electric Power Planning and Conservation Act in 1980 which authorized the states of Idaho, Montana, Oregon and Washington to create a entity to plan for two important resources in the Columbia River basin: electricity, and fish and wildlife. The entity created was the Pacific Northwest Electric Power and Conservation Planning Council, best known as the Northwest Power Planning Council. To emphasize the importance of fish and wildlife, Congress mandated that the Council develop the Columbia River Basin Fish and Wildlife Program before developing a power plan.

The Council has established the doubling of the salmonid runs of the Columbia River as a primary goal of its Fish and Wildlife Program. Achievement of this objective could result from: (i) an increase in the production of hatchery salmon, (ii) increases in the production of natural spawning salmon, and (iii) increase in the downstream survival of juveniles. All three factors are likely to be involved in a truly successful stock rebuilding effort. Many management actions have been taken in an attempt to increase downstream survival, including: (i) fish bypass facilities: screens that divert juvenile salmon from the turbines, passing them through the dam in a separate water system, (ii) transportation: juvenile salmon collected at the fish bypass facilities and transported via barge below Bonneville Dam where they are released; (iii) increased flow during periods of smelt migration: augmenting the spill of water over the dam bypassing the turbines; (iv) predator control: reducing the population of northern squawfish (*Ptychocheilus oregonensis*) in the reservoirs. Each of these actions is directed toward increasing the survival of fish from the time of release until they enter the lower river below Bonneville Darn. While fish bypass facilities have been evaluated using fin-clipped or freeze-branded fish, and transportation evaluated using coded-wire-tags, to date no attempts have been made to evaluate increased flow or predator control efforts.

One of the guiding principles of the Fish and Wildlife Plan is adaptive management - learning by past actions. Until managers are able to evaluate reliably the effectiveness of their actions, learning will be slow. Changes in flow and other factors associated with downstream survivals to some extent can be evaluated by in-river mark recapture experiments, and such experiments are certainly an essential part of any well-designed attempt to evaluate water flow. However, this is not practical on a big enough scale to encompass all hatchery stocks, nor would such an in-river mark recovery program measure impacts that might occur once the fish leave the river.

Most studies of the relationship between flow and survival have concentrated on in-river measurements and comparison, primarily using freeze branding to measure travel times. Such studies have no way of examining the impact of changes in flow on survival after the fish pass through the dam system. A potential source of such data is the coded wire tag (CWT) data base. Since the early 1970s thousands of groups of hatchery and wild fish have been tagged on the Columbia, and the commercial and recreational fisheries, and escapements to hatcheries have been systematically sampled to obtain tag recoveries. CWT data have been routinely used by the Pacific Salmon Commission (PSC) working groups to estimate survival of Columbia River stocks.

The purpose of this study is to investigate the potential for using the CWT data base to examine the relationship between in river factors (especially flow) and survival in Columbia River chinook salmon.

Methods and **Results**

Estimating Survival from Coded-Wire-Tag data

Since the early 1970s approximately 2600 individual groups of chinook salmon have been marked with CWTs on the Columbia River. These tags have been applied primarily at hatcheries, although there has been some marking of wild stocks, and some of fish collected at darns. The motivation for tagging has been quite diverse, but most tags have been applied to compare experimental hatchery treatments, such as size and time of release, feeding regimes, or other hatchery practices. The data base on CWT data denotes three primarily types of tagging, experimental, production and index. Experimental tag groups are those mentioned previously, where agencies are experimenting with hatchery practices in some way. Production groups are fish reared under normal hatchery conditions and tagging is done in order to determine the contribution of the bulk of the hatcheries release to fisheries and return to escapement. Index tag codes are specifically designated for use in evaluation of fishery management practice.

For the purposes of examining the impact of in-river conditions on survival, the production and index tag codes are preferable because they have not been subjected to any experimental treatments. However, many experimental groups appear to have similar survival to the hatchery production groups, and since far more releases are experimental than either production or index, we may not want to exclude experimental groups out of hand.

Since the aim of this project is to examine the relationship between in-river flow and the subsequent survival, we must have CWT groups released from a range of flow conditions. Figure 1 shows the average flow at McNary dam in May, from 1976 to 1989. The amount of variation in flow is not great, but there is a little more than two times variation from the lowest year, 1977 with a flow of 150,000 cfs, to the highest year 1976 with an average flow of 350,000 cfs.

Figure 1 near hera

The highest flows occur in May and June, with declining flows in July and August. Figure 2 shows the seasonal pattern of flow for 1976 to 1988. There is a high correlation in flows between months (Table I), generally 0.8 or higher.

Figure 2 near here
Table 1 near hera

We searched over all available CWT codes for hatcheries that met two conditions, (1) the hatchery must be upstream of McNary dam so that the juveniles had to pass through the four lower river dams at a minimum, and (2) there must have been non-experimental tagging over a number of years with contrast in flow.

Unfortunately, only Priest Rapids hatchery met these conditions. None of the Snake River hatcheries had consistent enough tagging to provide a usable base of data, and none of the other hatcheries on the mainstem above McNary darn had more than occasional tagging. Priest Rapids, in comparison, had consistent production or index tagging from brood year 1975 to the present time. Only three of the tag groups at Priest Rapids hatchery were experimental. In recent years a number of *other* hatcheries have begun systematic tagging of index or production groups, and within 5 or 10 years there will be a much bigger base of available hatcheries. However, at present, only Priest Rapids hatchery provides enough tag groups over enough years to examine the relationship between flow and survival

For any CWT group, we can estimate the survival from release to any arbitrary age using the method of Virtual Population Analysis (vPA). This method is routinely used for chinook salmon by the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC), and the method is described in Hilborn and Walters (1992). Because chinook salmon mature at a variety of ages, the most common convention is to calculate survival to age 2 (S) using the following equation:

$$N_2 = \sum_{a=2}^{a=6} \frac{R_a}{p_a}$$
$$S = \frac{N_2}{T} \qquad (1)$$

where N2 is the number of individuals surviving to age 2, R_a is the number of tags in the catch and escapement at age a, Pa is the probability of surviving from age 2 to age a, and T is the total number of tagged fish released. This equation assumes that the P's are known, and that there is no loss of fish except to capture and escapement, and that all fish spawn by age 6. The estimates of S naturally are sensitive to the assumed probability of survival from age 2 onward, but if we consider S to be an index of survival, then the choice of P's makes little difference in the relative survival. We used the same P's as the CTC which are 1,.6,.42,0.336 and 0.3024 for ages 2,3,4,5 and 6 respectively.

The two factors not included in the method described above are incidental fishing mortality and inter-darn loss during up-river migration. The CTC has developed a variety of methods to deal with incidental fishing mortality which rely on a number of assumptions. We have chosen to ignore incidental fishing mortality primarily because we will be comparing survival of different code groups subjected to the same fisheries, and changes in incidental fishing mortality will affect all groups equally.

Appropriate statistics and results

Figure 3 shows the relationship between the flow at McNary dam during the month a CWT group was released, and the estimated survival for that CWT group using the VPA equation given above. The solid line is the best linear regression fit. The estimated intercept is 0.02 so it appears the line passes through the origin. We see a general trend towards higher survival with increasing flow, but there is considerable scatter about the graph, with the data points for 1977, 1984 and 1985 all lying well above the best fit line, and most other points lying below.

Figure 3 near here

We could calculate the statistical significance of the regression shown in Figure 3, and use this to test the hypothesis that there is a significant relationship between flow at McNary darn and the survival of the fish released from Priest Rapids hatchery. There are three major problems with such an approach. Fret, hypothesis testing is inappropriate for decision-making, while the major interest in the relationship between flow and survival is due to the need to make decisions about the management of the hydroelectric system. Second, it is statistically inappropriate to use survival rates as the y variable in a linear regression. This ignores both the potential for differential reliability of different survival rates, and the fact that survival rates cannot have values less than zero. Third, many of the changes seen in survival at Priest Rapids hatchery have been seen at other chinook hatcheries on the Columbia River which are below the darn system. Therefore some of the changes seen in survival could result from changes in ocean rather than in-river conditions. In trying to determine in-river survival changes, we first must attempt to correct for ocean changes. We will deal with each of these problems in turn.

The traditional mode of statistical analysis in fisheries biology is hypothesis testing which typically considers two hypotheses, the null hypothesis, that there is no relationship between flow and survival, and the working hypothesis, that there is a relationship. first one chooses an *a* level, the probability of rejecting the null hypothesis if it is true, and then determine p, the probability that the data could have been obtained if the null hypothesis is true. If p is less than α the null hypothesis is rejected and one concludes that flow affects survival.

Such an approach has little if any utility, particularly in the context of natural resource management (Hilborn and Ludwig, 1993). First, one must determine *a,* a totally arbitrary decision. Secondly, if we fail to reject the null hypothesis, do we act as if there is no relationship between flow and survival? If we do reject the null hypothesis, how much flow do we allow?

The appropriate statistics for analysis of decisions is statistical decision theory (Raiffa 1968). One examines the consequences of alternative actions for different possible states of nature (relationships between flow and survival). Statistical decision theory considers a wide variety of alternative states of nature and their probabilities. The appropriate product for use in statistical decision theory is the probability distribution of different relationships between flow and survival. Rather than considering only a null hypothesis and a working hypothesis, rejecting one and accepting the other, we want to determine how likely alternative states of nature are. Berger (1985) provides a reference on statistical decision theory, and Hilborn et al. (1993) provide a discussion and example of how these methods can be used in fisheries management.

As a simple example, consider that the only parameter of interest is the slope of the flow-survival relationship. We want to estimate the probability of different slopes. The appropriate model (ignoring the considerations regarding using survival as the y variable mentioned above) is

$$\hat{s}_g = \bar{s} + a(F_g - \bar{F}) + e_g \qquad (2)$$

where s_g is the predicted survival rate for code group g, a is the slope between flow and survival, $\bar{s}$ is the average survival for the data set, F_g is the flow affecting code group g, $\bar{F}$ is the average flow, and e_g is a normally distributed random error. The likelihood of the data for any value of a is the normal likelihood

$$L(S|a) = \prod_g \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{(s_g - \hat{s}_g)^2}{2\sigma^2}\right) \qquad (3)$$

If we consider a set of discrete hypotheses about the slope, and assume that we know σ, then the Bayes posterior distribution for any given level of a is

$$\Pr(a_i|S) = \frac{L(S|a_i)\Pr(a_i)}{\sum_j L(S|a_j)\Pr(a_j)} \tag{4}$$

where $\Pr(a_i \mid S)$ is the posterior probability distribution for a and $\Pr(a_i)$ is the prior probability we assign to alternative a values. If we consider n discrete hypotheses about a, and assign them equal probability I/n, we can compute the Bayes posterior probability from the data shown in Figure 4.

Figure 4 near here

We cart see from Figure 4 that it is most likely that higher flows have been associated with higher survival. A traditional statistical analysis would reject the hypothesis that there is no flow-survival relationship at an a of 0.05, but fail to reject the hypothesis at α=0.01. The probability distribution shown could be used by decision makers to weigh the consequences of alternative flow regimes. This example ignored two major considerations mentioned above, the statistical properties of survival estimates, and the trends in ocean survival seen in other hatchery stocks on the Columbia River.

Appropriate statistical model

Survival rates for the CWT groups are not directly observed, but are computed using equation 1. What is actually observed is the number of tags recovered from catch and escapement sampling, the number of marked fish released, and the proportion of catch or escapement that is actually sampled. The two most common methods of dealing with survival data are to use either arcsine or logit transforms. However, with the advent of modem desktop computer hardware and software, many explicit statistical models can be applied to survival data. Lebreton et al. (1992) review general procedures for mark-recapture analysis, while Green and MacDonald (1987), and Cormack and Skalski (1992), Schnute (1992), and Pascual (1993), specifically discuss CWT data. All of these methods model the number of observed recoveries as a multinominal or poisson process. The basic likelihood of the observed recoveries, given the predicted under the poisson probability is

$$L(O|E) = \frac{E^O}{e^E O!} \tag{5}$$

where O is the number of observed recoveries and E is the number of expected recoveries under the hypothesis. The expected recoveries can be written as:

$$E = Ts\frac{1}{f} \tag{6}$$

where T is the number of tags released, s is the survival, and f is the proportion of catch or escapement that is sampled for tags.

The methods described in Green and McDonald (1987), Cormack and Skalski (1992) and Pascual all consider a large number of space/time strata for recovery of tags. We will employ this method in a later section, but first we will use the basic approach to consider the overall survival rate in a realistic statistical context.

In the VPA we used the number of estimated recoveries by age (R_a), and inflated these by the estimates of survival to arrive at an estimate of the number alive at age 2. We could consider the number alive at age 2 (N_2) of equation 1 as the "observed" recoveries and treat them as poisson distributed random variables. In reality, only a fraction of the catch or escapement is sampled – commercial fisheries are usually sampled at about 20%, while escapement may be sampled at a higher rate. In our first analysis, we have assumed that the actual "observed" recoveries is 20% of N_2 -- that is:

$$\begin{aligned} O &= fN_2 \\ E &= Ts\frac{1}{f} \\ f &= 0.2 \end{aligned} \tag{7}$$

We then can calculate survival as a function of flow, use the survival term in equation 7 to obtain predicted recoveries, then use equation 5 to calculate the likelihood analogous to equation 3. In the next section we will write the entire likelihood.

The multinomial and poisson probabilities are the most frequently used for mark-recapture analysis and are usually justified based on sampling theory. However, when there are sources of error other than sampling, the variance in the data is often is much higher than predicted from multinomial or poisson distributions. This is almost always the case in CWT data, where variability in number recovered often comes more from sampling than from variation in survival rates (Pascual 1993). Statistical tests of hypotheses thus are performed using the scaled poisson distribution which allows for over-dispersion. Use of the scaled poisson is discussed later.

An alternative to the scaled poisson distribution is to treat the observed recoveries as lognormal variables. The lognormal is a robust statistical model that is frequently used, however, it does not perform well when individual observations are few and cannot be used at all when there are zeros in the data. In the case of our data there are no zeros, so we can use the lognormal model as an alternative to the poisson model. The lognormal likelihood is:

$$L(O|E) = \frac{1}{\sigma\sqrt{2\pi}}\exp(\frac{(\ln(O) - In(E))'}{2\sigma^2}) \tag{8}$$

Correcting for trends in ocean survival

Figure 5 shows the trends in survival estimated from VPA for a number of Columbia River chinook hatcheries. These data include all CWT groups, including experimental groups. Priest Rapids, Cowlitz and Washougal all show unusually good survival among fish released in 1985 and 1985 and poorer survival among fish released in 1986 and 1987. The Grays hatchery does not show this trend, and Bonneville has so much variability that it is difficult to see any pattern, although 1984 and 1985 do have some especially good survivals.

Figure 5 near **here**

In order to separate the affect of flow on survival, we need to control for changes in ocean conditions. This can be done by using CWT groups released below the dam system. This assumes, of course, that the impact of flow on survival takes place within the dam/pool system and not in the estuary or early ocean Life history. The model we will use can be written as follows:

$$\hat{s}_g = G \times H_g \times Y_g \times M_g \times (1 + a(F_g - \bar{F})) \quad \text{if Priest Rapids hatchery}$$
$$\hat{s}_g = G \times H_g \times Y_g \times M_g \times 1 \quad \text{if control hatchery} \tag{9}$$

where G is an overall grand mean survival, H_g is a hatchery effect, Y_g is a year of release effect, M_g is a month of release effect, a is the slope of the flow-survival relationship, F_g is the flow during the month CWT group g is released, and $\bar{F}$ is the average flow.

Choice of best matching hatcheries

Before we can begin with a formal analysis of in-river factors and survival we must obtain suitable control stocks from the lower Columbia River to control for ocean effects. Thus a key objective of this portion of the study was to determine the ocean catch distributions of individual stocks of chinook salmon from the Columbia River. To our knowledge, a complete study of the ocean catch distribution of Columbia River chinook salmon has not been undertaken. Healey (1983, 1991) was able to demonstrate that two different races of chinook salmon (stream and ocean type) exist along the Northeastern Pacific coast and each race had somewhat different oceanic distributions. Snake River fall chinook (ocean type) were shown to have an oceanic catch distribution that was primarily off the British Columbia, Washington, and Oregon coasts, while spring chinook (stream type) have a more northerly catch distribution (Waples et al. 1991). Catch data are used by investigators to infer ocean distribution. The obvious problem with this is that the fishery is limited in both space and time. Generally the fishery is conducted during the summer and early fall months and is limited to the waters within about 200 miles of the shore. Columbia River chinook salmon are captured from Northern California to Alaska in both the commercial and spon fisheries. Tagging experiments (Healey 1991) have shown that chinook salmon appear to move about the North Pacific Ocean in a pattern that takes them north in the summer and south in the winter. Fall chinook in particular appear to be located within 1000 km of the North American coast. However, individual stocks may show different migration patterns. Managers also know that individual stocks have a propensity to be caught in different regions of the *Northeast* Pacific Ocean.

Coded Wire Tag (CWT) data were used for this task. CWTs are stainless steel binary-coded tags imbedded in the nose cartilage of juvenile salmon at hatcheries. Fish from the same group share the same code, therefore the tag identifies each fish with a specific treatment group from a specific hatchery. The presence of the CWT tag is indicated by the removal of the adipose fin on all anadromous salmonids except hatchery steelhead which have the adipose fin removed whether they have a CWT or not. Some natural spawning juvenile salmonids have been caught and tagged with CWTs, but the temporal and spatial coverage is not extensive. Commercial and recreational catches of salmonids are sampled for the presence of CWTs by fisheries management agencies who attempt to sample 20 percent of the catch. When adult fish return to the hatchery, they are also examined for the presence of tags. Therefore, the CWT data base consists of the number of juvenile salmonids tagged and released, the recoveries of tagged fish in commercial/recreational fisheries, and the number of tagged fish in the escapement. We gathered all the chinook salmon CWT releases of both the Columbia River hatcheries and of the wild stocks along with the corresponding ocean recovery data. The recoveries were expanded by the sampling fraction, and these expanded numbers were used for analysis. Review of the available data indicated that catches in small geographic areas were limited and therefore considered unreliable.

The expanded recoveries were grouped by State or Province, and by year of recovery. For each stock and year of release, a matrix of age at recovery and area of recovery (State or Province) was generated, and comparisons were made using a cluster program (SPSS/PC) that generated a distance matrix. Since we wanted to compare ocean catch distributions between stocks, we compared distributions across all years. The resulting matrix showed calculated distances (affinities) between stock distributions, the smaller the number the closer the affinity.

We wanted to find hatcheries that met three criteria (1) they were below Bonneville Dam, so that the fish were not passing through darns, (2) there were as many years as possible of CWT data, and (3) the stock showed as similar as possible ocean distribution to the Priest Rapids stock. Given these requirements, the four other hatcheries we chose, based on the criteria are Bonneville hatchery, Cowlitz hatchery, Grays hatchery, and the Washougal hatchery (table 2); spring creek is also included as an example of a hatchery with an ocean distribution quite different from Priest Rapids. As seen earlier in Figure 5, Cowlitz and Washougal hatchery stocks showed similar patterns in ocean survival to the Priest Rapids stock. The Bonneville and Grays River survival patterns were more variable but showed some similarity to the Priest Rapids trends. The ocean spatial distributions are shown in Figure 6. In general, priest Rapids, Bonneville, Cowlitz, Grays River and Washougal all showed a preponderance of tag recoveries from British Columbia with smaller proportions from Alaska and Washington. Recoveries in Oregon and California were limited indeed. By way of contrast, Spring Creek (with a much higher affinity) tag recoveries occurred in almost equal proportions from British

Columbia and Washington, followed by Oregon, with Alaska and California showing very small recoveries.

Table 2 near here.

Figure 6 near here.

General issues in choice of tag groups

Having chosen Bonneville, Cowlitz, Grays and Washougal as control hatcheries, we need to select which CWT groups from these hatcheries to use. We used three primary criteria for selection; first we rejected any codes that were not released in the first summer after hatching, second we rejected any codes not released during the months of May, June, July or August, and third we initially rejected any experimental release groups. Figure 7 shows the trends in survival among the code groups selected. Cowlitz is the only hatchery that has a tagging history comparable to Priest Rapids, Bonneville and Washougal have almost no releases between 1983 and 1986, and Grays shows no trend (and quite low survival).

Figure 7 near here

Testing alternative models

We fit a series of increasingly complex models, starting first with only a grand mean, then allowing for year effect, hatchery effect, month effect, and a flow effect. When using poisson models, the test of hypothesis is performed by analysis of deviance (McCollough and Nelder 1989), which is analogous to analysis of variance. The deviance for any model fit is defined as

$$D_M = 2[\mathcal{L}(O|E) \ -2(010)] \qquad \text{(lo)}$$

where DM is the defiance of model M, $\mathcal{L}(O|E)$ is the negative log likelihood of the data given the model (equation x), and $\mathcal{L}(O|$ O) is the negative log likelihood of the data given the data, computed by substituting the observed values for the expected values in equation 5. The results of this analysis of deviance are presented in Table 3. As we add factors to the model, we determine how much the deviance is reduced (A deviance). The residual deviance is the deviance of the "full model" (model 1) which is the most complex . model we consider. The deviance of model 1, divided by the degrees of freedom of model 1 is the scale factor. If the error is truly poisson distributed the scale factor would be 1. Clearly there is much more unexplained variation in the data than expected under the poisson. The change in deviance from one model to the next divided by the scale factor is the delta scaled deviance. The delta scaled deviance is χ^2 distributed with the number of degrees of freedom that are different between the two models being compared. For instance, the change in deviance between model 1 and model 2 is 170.41. Divided by the scale factor we obtain a delta scaled deviance of 9.47, with 1 degree of freedom. The probability of χ^2 with 1 degree of freedom being 9.47 is 0.0018. We can see that all factors added to the model are highly significant.

Table 3 near hem

Table 4 shows the parameters estimated by the full model. There are no real surprises here. Year effects are seen in the Cowlitz and Priest Rapids data, all hatcheries except Grays have better average survivals than Bonneville, and May has the highest monthly survival. The estimated flow slope (a) is 0.0030. This means that an increase in flow from 200 kcfs to 300 kcfs would result in a 30 percent increase in survival.

Table 4 near here

A lognormal error model

If the error is poisson, the expected ratio of the residual deviance to the number of residual degrees of freedom is 1. The value shown in Table 3 is 17.49. Thus there is much more variability in the data than expected under the assumptions of the poisson. While this is commonly found in other analyses of CWT data (Green and MacDonald 1987, Cormack and Skalski 1992, Pascual 1993), in this instance we are dealing with a heterogeneous set of hatcheries and aggregating the data in several ways over many years, all of which may contribute to the large amount of unexplained variability.

An alternative approach is to assume that the estimated total recaptures are lognormally distributed, as in equation 8. We can repeat the analysis using the lognormal error, except that we now can use the likelihood ratio, to test alternative models.

In fitting nested models, the likelihood ratio test can be used to compare model i to model j as follows:

$$R(M_i, M_j) = 2(\ell(data|M_j) - \ell(data|M_j)) \qquad (11)$$

where $R(M_i, M_j)$ is the likelihood ratio of model i to model j. R is theoretically χ^2 distributed with number of degrees of freedom lost moving from model j to model i.

We estimated the σ by fitting the full model, as follows:

$$\hat{\sigma} = \sqrt{\frac{1}{n}\sum_{g=1}^{n}\left[\ln(O_g) - \ln(E_g)\right]^2} \qquad (12)$$

Table 5 near here

The value for $\hat{\sigma}$ is 0.45. The results with the nested model is shown in Table 5. We can see that the addition of all of the terms is clearly significant, and that the estimated slope is .0065, considerably higher than obtained with the poisson model. Given that the poisson distribution underestimates the error, we believe that the lognormal model is preferred, and the best estimate of the slope of the flow survival relationship is 0.0065.

The estimated parameters are shown in table *6.*

Table 6 near here

We would like to obtain a Bayes posterior distribution for the slope, but in theory this would require integrating across all nuisance parameters, including the year effects, hatchery effects, and month effects, as well as specifying a prior distribution for these parameters. However, we can use a shortcut: if we define the prior distributions for all nuisance parameters as uninformative, then when discretized and normalized to add to 1.0, the likelihood profile for the parameter is the marginal Bayes posterior for the parameter (Berger 1985). Given that we have no strong a priori feelings about nuisance parameters, we are happy to assume an uninformative prior about them.

To calculate the likelihood profile we simply fix the slope at a value, then maximize the likelihood by searching over all other parameters. We repeat this calculation over a range of slopes of interest. We then divide each likelihood by the sum of all the Likelihoods which normalizes them. Figure 8 shows the approximate marginal Bayes posterior for the slope of the flow-survival relationship using this method and assuming the log normal likelihood-

Figure 8 near here

The major purpose of using the hatcheries other than Priest Rapids is to calculate the year effects and month effects. We have seen that the statistical model finds a good relationship between flow and survival. We can see this graphically in Figure 9, where we have computed a “corrected survival" by the following formula:

$$^{corrected}S_g = \frac{S_g}{Y_g M_g} \qquad (13)$$

Thus if the year effect were .5 and the month effect was 1, then the corrected survival would be twice the observed survival. The absolute value of the survivals in Figure 9 is arbitrary. The key points to observe is that the relationship between flow and survival now appears less variable than it did in Figure 3, and the year effects have served to bring the data closer together. In particular, the year effects for 1977, 1981, 1984, and 1985 were larger than average, bringing these points into the main cluster of data.

Figure 9 near here

We next repeated the log normal analysis combining all experimental codes with the brood and index codes to determine how sensitive our results are to choice of codes. Table 7 shows the results - again a highly significant flow-survival slope.

Table 7 near here

Finally, we used the actual recoveries (not expanded by the sampling fraction) as the observed value. We then used the lognormal model, estimated the slope. and tested to see if adding the flow relationship significantly improved the fit. Table 8 shows that the change in negative log likelihood is 3,86, about twice that required to be significant at the

.05 level, and the estimated slope is 0.0060, close to that estimated earlier. Thus we conclude that our results are quite robust with respect to how we treat the recovery data

Table 8 near here

Alternatives to VPA -- commercial ocean recoveries

A potential weakness of VPA is that the in-river catches and escapements are often difficult to sample. There may be considerable loss of adult fish between passage at Bonneville dam and recapture in fisheries or escapement. As a control on the freshwater recoveries of tags, we performed an analysis using only marine recoveries and employing the basic Generalized Linear Model format adopted by Green and MacDonald (1987), and Cormack and Skalski (1992). We broke all recoveries down by age of fish, and state or province. Thus the model is:

$$R_{g,l,a} = T_g f_{y,l} \exp(G + H_g + Y_g + M_g + L_{g,l,a} + A_{g,l,a} + HL_{g,l,a} + HA_{g,l,a} + a(F_g - \overline{F})) \quad (14)$$

where $R_{g,l,a}$ is the number of observed tags recovered from group g at location 1 at age a, T_g is the number tagged in group g, $f_{y,l}$ is the sampling fraction in the year and location that age a tags were recovered from group g, G is the grand mean, H_g is the hatchery affect for the hatchery for tag group g, Y_g is the year effect for the year of release of tag group g, M_g is the month effect for the month of release of tag group g, $L_{g,l,a}$ is the location effect for the location of the recoveries from tag group g,l,a, A is the age effect for the tags from g,l,a, HL is hatchery by location interaction, HA is hatchery by age interaction, a is the slope of the flow-survival relationship, and F_g is the flow at McNary darn during the month of release, if the group is from Pries Rapids hatchery, and the flow is equal to the average flow for ($\overline{F}$) other hatcheries.

Table 9 shows the analysis of deviance. Note that by disaggregating the data into location and age of recovery, the scale factor is now reduced to 3.78 from 17.41 in the previous poisson analysis. We again found that the all factors are significant.

Table 9 *near* here

Table 10 shows the main effects parameters estimated from the model, the estimated parameter value from the logarithmic model, the standard deviation of the estimate, and the transformed value which tells us the actual multiplicative effect of the parameter. The grand mean is standardized as follows: release year 1977, Bonneville hatchery, May releases, recoveries in California at age 2. Thus we see that the year effects are quite similar to that estimated previously. 1977, 1984 and 1985 stand out as the best years. The hatchery effects are also similar, except that Washougal hatchery has a much higher multiplier -- presumably because a greater portion of the recoveries of Washougal fish were from marine areas. The month effects again show June weaker than May. The location of recovery effects are new to this model, and all show that California (the base case) is very weak, with B.C. the largest effect, Washington and Alaska roughly half of B. C., and Oregon a distant fourth.

Table 10 near here

The slope of the flow-survival relationship is lower, suggesting that a 100 kcfs increase in flow would result in a 26 percent increase in survival, rather than 65 percent as suggested in our previous analysis.

Discussion

These results show a significant conflation between flow at McNary darn and survival of Priest Rapids hatchery fish - evidence that higher flows would lead to better survival of Priest Rapids fish, and by analogy that higher flows in the Columbia and Snake Rivers would lead to better survival of hatchery and wild stocks throughout the entire Columbia and Snake river basins. This is an important conclusion in terms of future management decisions for the entire Columbia Basin.

There are obviously many other in-river conditions that could be examined in relation to survival, including temperature, barge transportation, turbidity etc. Even with flow alone it is possible to use many different measures such as total flow, spill,and the ratio of spill to water passed through the turbines. Many different averaging methods also can be used. We chose the simplest which is flow during the month of release, but clearly the fish are in the river for many weeks after release.

We did not consider it appropriate to do a wide scale comparison of correlations between other environmental variables. Undoubtedly some of these variables would be more correlated than the flow we have chosen and others would be less. Any extensive set of comparisons would suffer from the problem that, if you look at enough variables, something will show a better fit.

A weakness in this study is the fact that all of these results deal with the flow-survival relationship for Priest Rapids hatchery only. A high priority should be to compare the results to other hatcheries as CWT data accumulate. Priest Rapids hatchery is one of the most successful in the entire Columbia Basin. The impacts of flow on Priest Rapids fish may be different from those on the upper Columbia or Snake River fish. Since Priest Rapids fish are sub-yearling migrants, the applicability of these results to the Snake River spring chinook, yearling migrants, may be limited.

While all of the statistical models we used did show a better survival with higher flow, the amount of increase in survival expected for a given level of additional flow was different for the different models. The lognormal error model using total recoveries suggested that 100 kcfs increase in flow would result in about 60 percent increase in survival, while the poisson model using only marine recoveries suggested a 20 percent increase might be expected. We do not feel confident in saying that one of these estimates is more likely to be correct than another. We believe the evidence is strong that Priest Rapids fish have survived better when flow has been higher. We are less confident about the expected increase in survival from increased flow. The analysis using marine recoveries has the advantage that the data were stratified by age and location of recovery, and one could argue that this is the preferred mode of analysis. However, in the absence of any Monte-Carlo simulations to compare the alternative models we have used, we cannot say with any certainty which of our estimates of the flow-survival slope are more likely to be correct.

The major weakness of this study is the non-experimental nature of the data available. We have simply shown a correlation. Our results are compatible with much of the biological understanding of the downstream migration process and the suggested changes in migration due to major impoundments. Nevertheless we have shown a surprising degree of correlation between flow and survival.

We have used several lower river hatcheries as controls on ocean survival. Our assumption was that the impact of flow on survival takes place above Bonneville Darn, and that flow would have no affect on lower river hatcheries. This could be a false assumption for several reasons. Flow undoubtedly affects estuarine conditions, and this could, in turn, be important in the survival of lower river hatchery stocks. Flow may be related to ocean conditions through regional weather patterns. Years of high rainfall and snowpack may coincide with years that ocean conditions are good (or bad) for Columbia River salmonids. By choosing lower river hatcheries as controls on survival, we have made several assumptions that are most difficult to verify.

This study is simply one small piece of evidence in determining the expected impact of different management actions on the survival of Columbia River salmon. It needs to be corroborated by further CWT studies, further in-river passage studies, and more ecological and physiological understanding of these fish.

There are a number of obvious next steps in analysis of CWT data for determining the flow-survival relationship. At the time this project was initiated the number of CWT groups available from Snake or upper Columbia hatcheries was small, and the survival at these hatcheries had been so poor that few recoveries were available. An examination of all recently available codes and recoveries should be done to see if and when other suitable time series might be available for comparison to Priest Rapids.

Monte-Carlo studies of different likelihood models, different levels of spatial and temporal aggregation, and the impact of using fresh-water recoveries should be explored. It maybe possible to understand the relative merits of different statistical models via such analysis.

This study has highlighted the importance of changes in ocean survival that impact many Columbia River stocks. Any attempts to understand the impact of in-river action on survival will be confounded by changes in ocean conditions. The poor returns of chinook salmon in the early 1990's are to a large extent almost certainly due to poor ocean survival, "whether or not they encounted dams. We would recommend that CWT.data be used to examine the historical pattern of survival of Columbia River fish, and to determine the spatial correlation among stocks. Such a study would be of great utility in assessing the success of mitigative actions up-river, and in evaluating the success of any rehabilitation programs that may be adopted.

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Appendix

List of tag codes and data for non-experimental release groups.

Tag Code	Hatchery	Brood Year	Date of Release	Number Released	"Estimated" recoveries	VPA Survival Estimate	Total expanded recoveries	Flow at McNary at time of Release
73328	Bonneville	86	8-May-87	105922	93	0.09	18.52	0
73006	Bonneville	86	8-May-87	52096	139	0.27	27.75	0
73632	Bonneville	86	8-May-87	51478	120	0.23	23.90	0
73326	Bonneville	84	20-Jun-85	206756	4281	2.07	856.29	0
72408	Bonneville	81	4-Jun-82	96798	163	0.17	32.52	0
72157	Bonneville	79	28-May-80	121071	288	0.24	57.53	0
72342	Bonneville	80	12-May-81	51609	152	0.30	30.47	0
72341	Bonneville	80	12-May-81	50805	218	0.43	43.67	0
71842	Bonneville	78	29-May-79	287916	1570	0.55	314.01	0
72329	Bonneville	80	12-May-81	75717	366	0.48	73.10	0
632154	Cowlitz	79	11-Jul-80	244267	746	0.31	149.27	0
632159	Cowlitz	79	I1-Jul-80	70474	201	0.29	40.24	0
632156	Cowlitz	80	28-Jun-81	153216	1819	1.19	363.74	0
634126	Cowlitz	86	19-Jun-87	207003	396	0.19	79.14	0
632255	Cowlitz	80	28-Jun-81	121271	717	0.59	143.36	0
632032	Cowlitz	81	8-Jul-82	41295	49	0.12	9.86	0
632462	Cowlitz	81	8-Jul-82	199176	972	0.49	194.47	0
633237	Cowlitz	84	19-Jun-85	48382	1159	2.39	231.71	0
633019	Cowlitz	83	21-Jun-84	48946	937	1.91	187.36	0
633020	Cowlitz	83	21-Jun-84	49036	1150	2.35	229.99	0
633124	Cowlitz	83	21-Jun-84	48829	868	1.78	173.59	0
633125	Cowlitz	83	21-Jun-84	49664	933	1.88	186.56	0
633235	Cowlitz	84	19-Jun-85	48634	1173	2.41	234.55	0
633236	Cowlitz	84	19-Jun-85	48246	1137	2.36	227.42	0
634108	Cowlitz	85	26-Jun-86	197500	1056	0.53	211.12	0
633238	Cowlitz	84	19-Jun-85	44126	1414	3.20	282.79	0
632503	Cowlitz	82	23-Jun-83	150236	1004	0.67	200.78	0
631802	Cowlitz	77	19-Jun-78	146001	1011	0.69	202.14	0
633759	Grays	85	28-May-86	49874	254	0.51	50.72	0
633760	Grays	85	28-May-86	50635	211	0.42	42.29	0
632458	Grays	81	1-Jun-82	27460	11	0.04	2.18	0
632459	Grays	81	1-Jun-82	45361	48	0.11	9.63	0
632263	Grays	80	8-Jun-81	64096	284	0.44	56.82	0
631646	Grays	78	9-Jun-79	73872	100	0.14	19.95	0
631833	Grays	78	9-Jun-79	7635	14	0,19	2.85	0
631937	Grays	78	9-Jun-79	68115	94	0.14	18.85	0
632043	Grays	79	24-Jun-80	37456	172	0.46	34.37	0

632340	Grays	80	1-Jun-81	10180	77	0.75	15.30	0
631743	Grays	77	26-May-78	143182	70	0.05	13.92	0
631939	Grays	78	5-Jun-79	92358	145	0.16	29.03	0
131615	Grays	76	16-Aug-77	15197	101	0.66	20.12	0
632155	Priest Rapids	80	24-Jun-81	194649	2227	1.14	445.32	357
632252	Priest Rapids	81	16-Jun-82	262176	3269	1.25	653.72	366
631857	Priest Rapids	78	28-Jun-79	17467	47	0.27	9.49	175
631958	Priest Rapids	78	28-Jun-79	5316	12	0.22	2.35	175
632848	Priest Rapids	83	13-Jun-84	74170	3541	4.77	708.11	343
632859	Priest Rapids	83	13-Jun-84	74392	3241	4.36	648.22	343
632860	Priest Rapids	83	13-Jun-84	74170	2640	3.56	528.04	343
631948	Priest Rapids	79	26-Jun-80	147145	1708	1.16	341.66	284
632261	Priest Rapids	80	18-May-81	42089	1190	2.83	238.03	235
632456	Priest Rapids	81	18-May-82	48700	994	2.04	198.76	331
634102	Priest Rapids	85	12-Jun-86	203534	2055	1.01	411.04	257
634128	Priest Rapids	86	25-Jun-87	201779	876	0.43	175.27	148
633221	Priest Rapids	84	11-Jun-85	103665	3977	3.84	795.44	185
633222	Priest Rapids	84	11-Jun-85	105224	4361	4.14	872.17	185
51915	Priest Rapids	86	5-May-87	48975	435	0.89	87.10	225
51916	Priest Rapids	86	5-May-87	49769	510	1.02	101.91	225
51917	Priest Rapids	86	5-May-87	49331	405	0.82	81.02	225
51918	Priest Rapids	86	5-May-87	48796	520	1.07	104.02	225
631662	Priest Rapids	76	27-Jun-77	147338	2646	1.80	529.12	120
631741	Priest Rapids	77	27-Jun-78	152532	1460	0.96	292.05	241
632611	Priest Rapids	82	24-May-83	204141	3708	1.82	741.62	302
632017	Priest Rapids	78	28-Jun-79	82243	129	0.16	25.74	175
631821	Priest Rapids	78	23-May-79	48130	725	1.51	145.04	231
632153	Washougal	79	30-Jun-80	314605	2384	0.76	476.88	0
632461	Washougal	81	6-Jul-82	170424	899	0.53	179.76	0
632251	Washougal	80	6-Ju1-81	278774	1318	0.47	263.57	0
634150	Washougal	86	19-Jun-87	207377	441	0.21	88.13	0
631641	Washougal	76	28-Jun-77	126007	3777	3.00	755.30	0
631803	Washougal	77	27-Jun-78	151399	1118	0.74	223.69	0

Figures

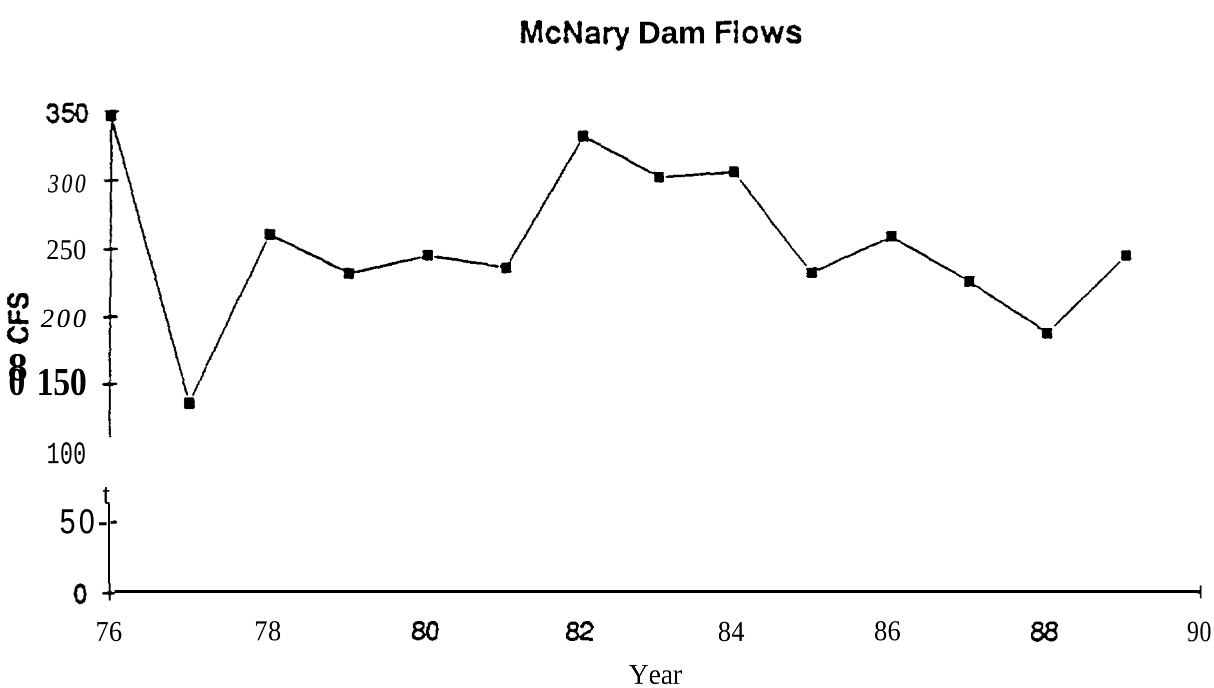

Figure 1. The average flow past McNary dam during the month of May.

McNary Average **Flow**

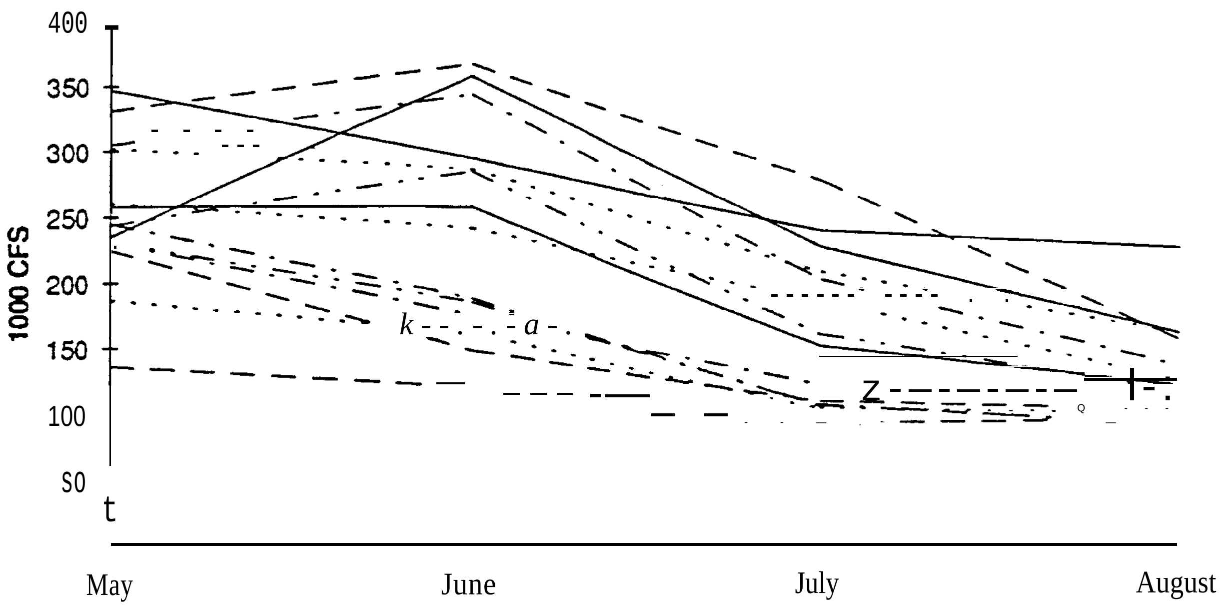

Figure 2. The average flow during May, June, July and August for the years 1976 to 1988

Priest Rapids

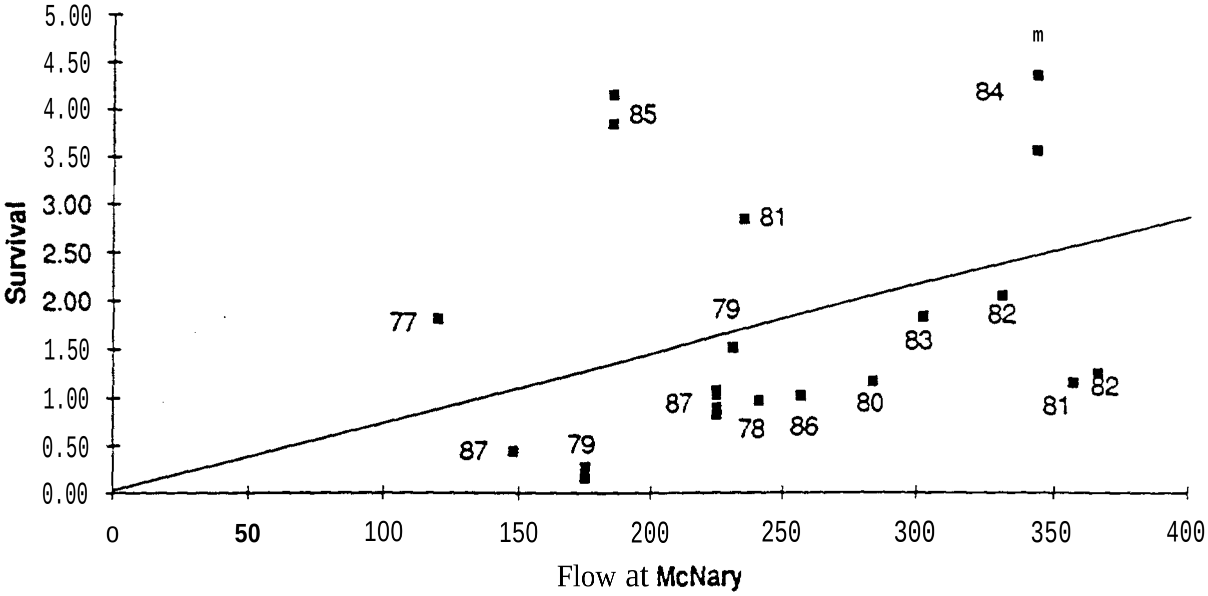

Figure 3. The relationship between flow at McNary *dam* during the month fish are released from the hatchery, and the estimated survival of the CWT group from VPA. The solid line is the best fit linear regression, not constrained to pass through the origin.

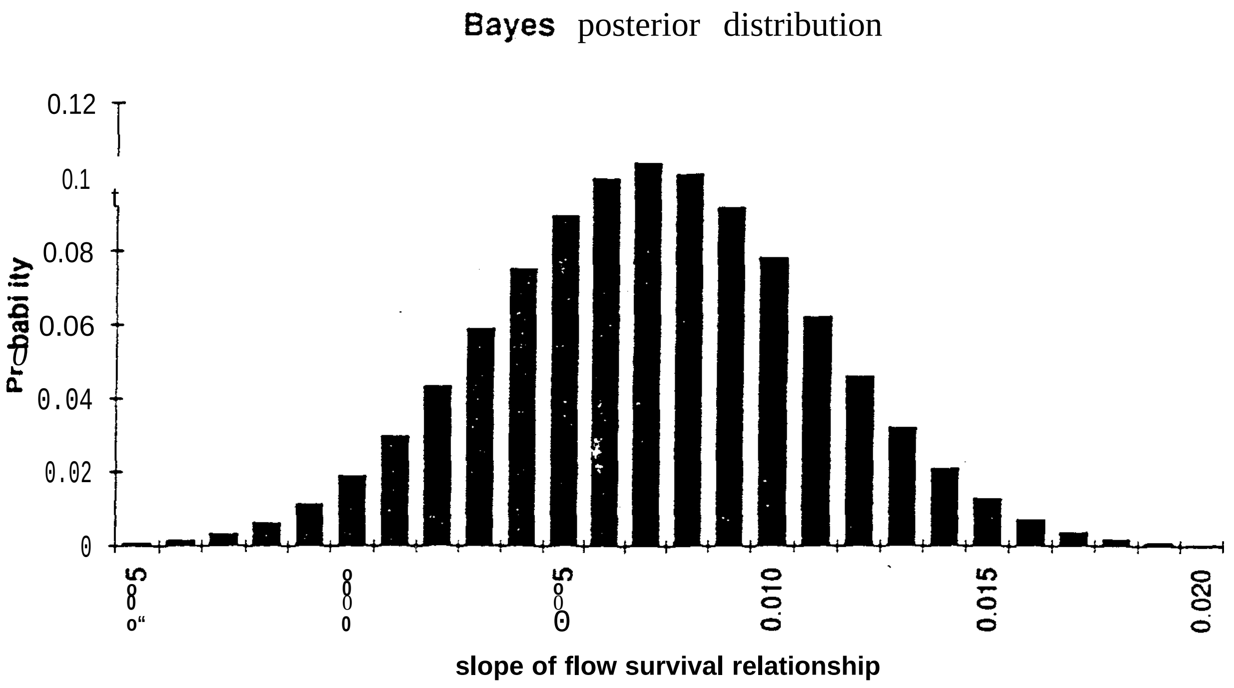

Figure 4. Bayes posterior distribution of the slope of the flow survival relationship from figure 3.

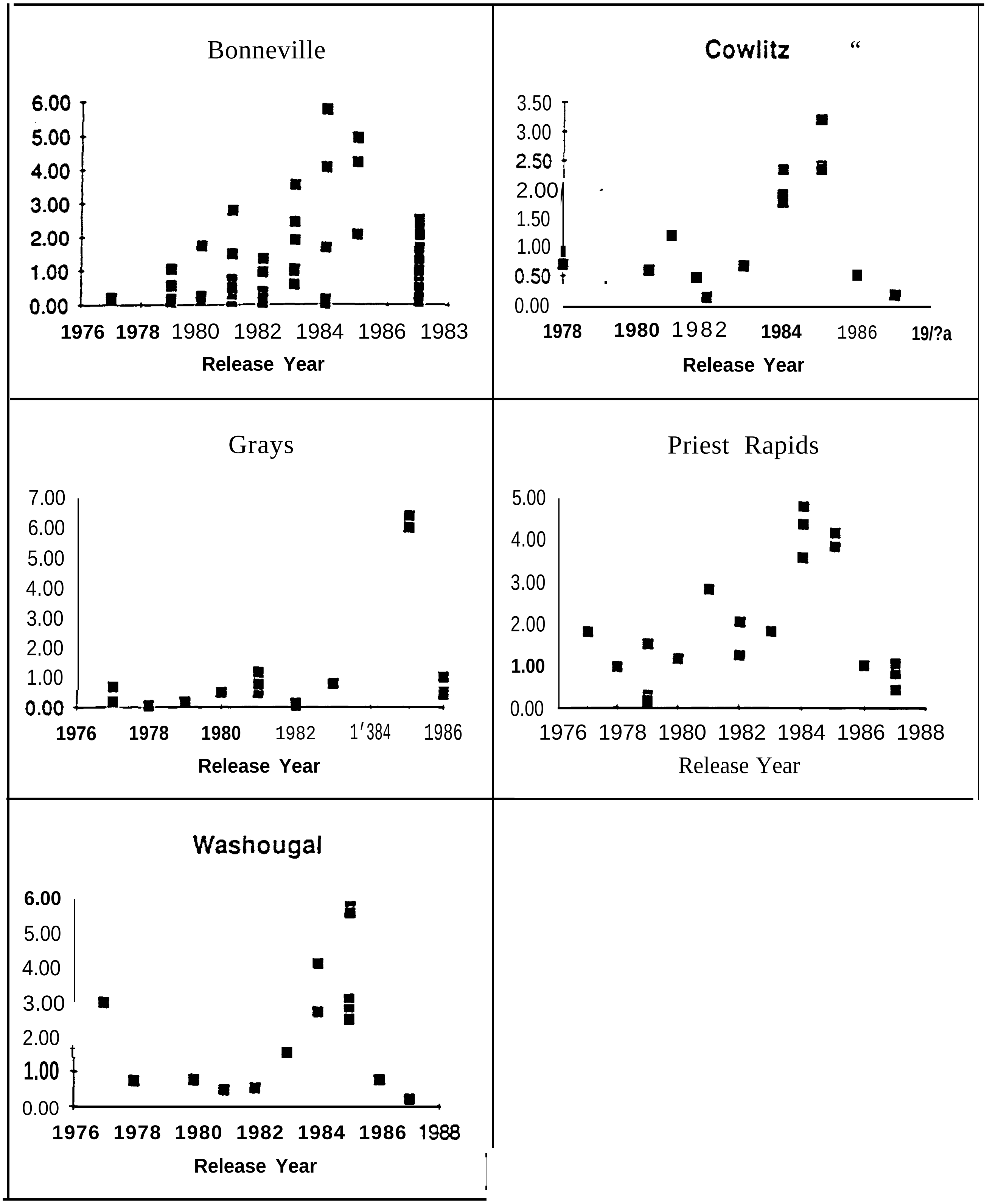

Figure 5. The estimated survival for five hatcheries for all CWT groups.

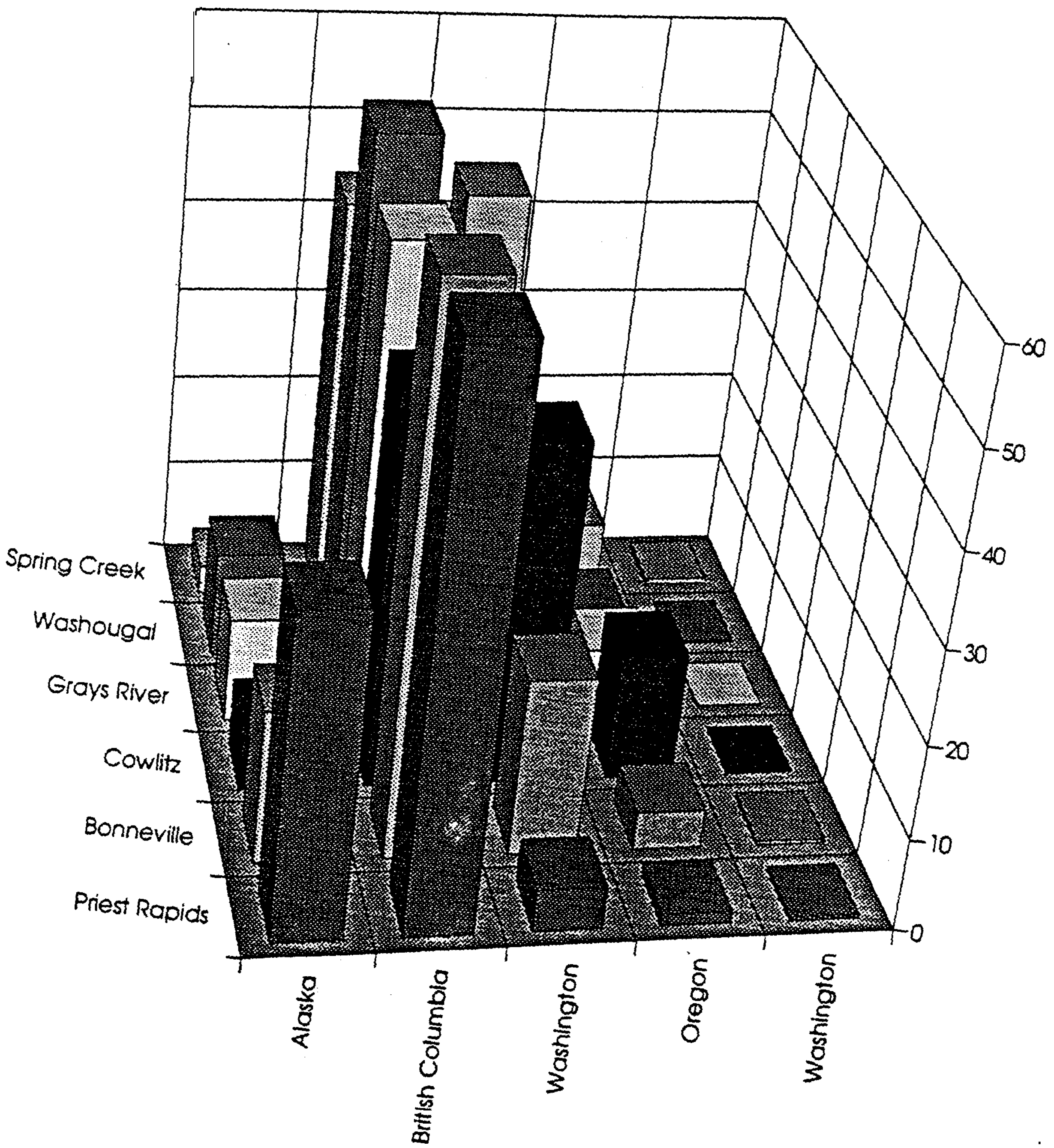

Figure 6. North south distribution of stocks

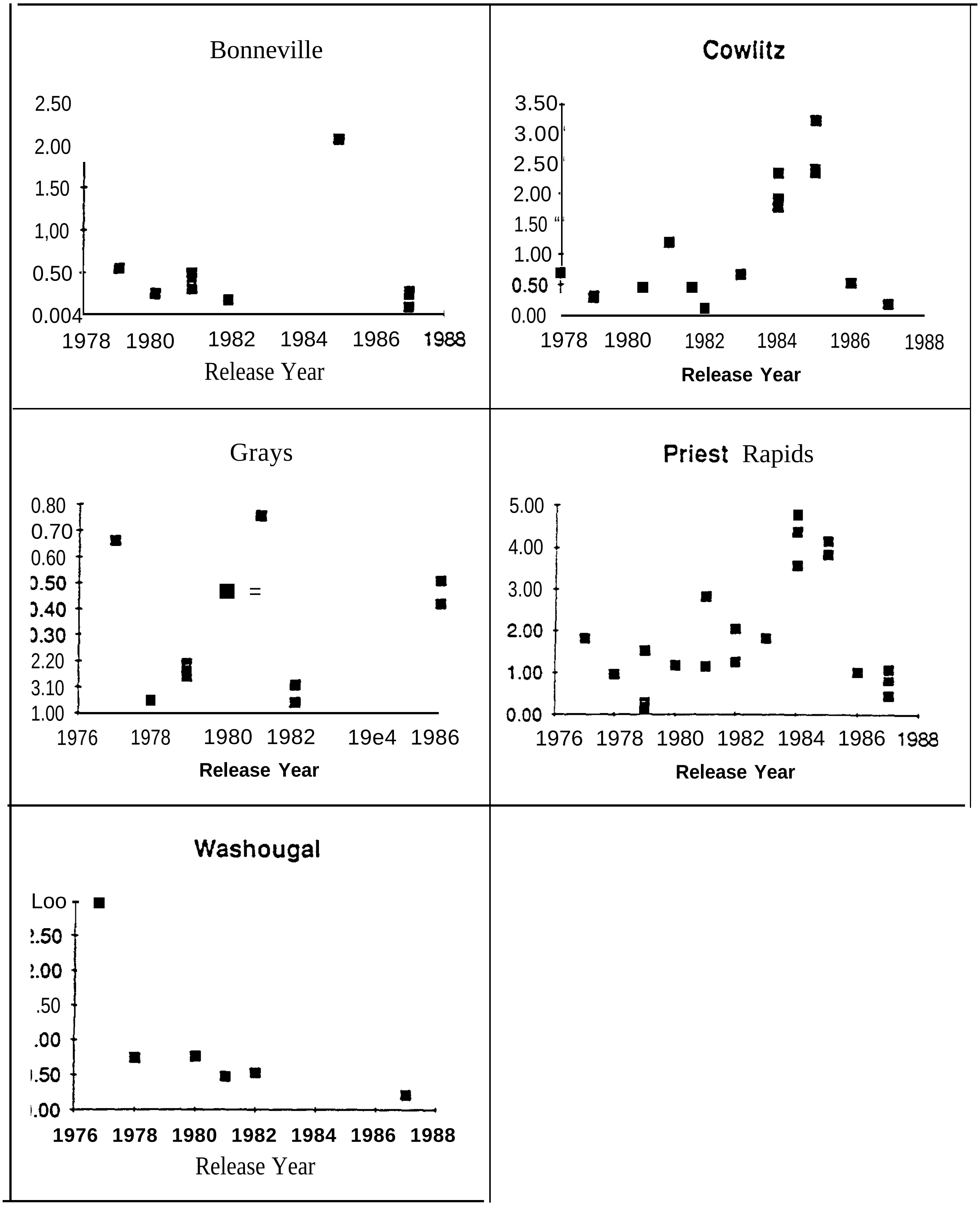

Figure 7. The estimated survival for five hatcheries using non-experimental CWT groups.

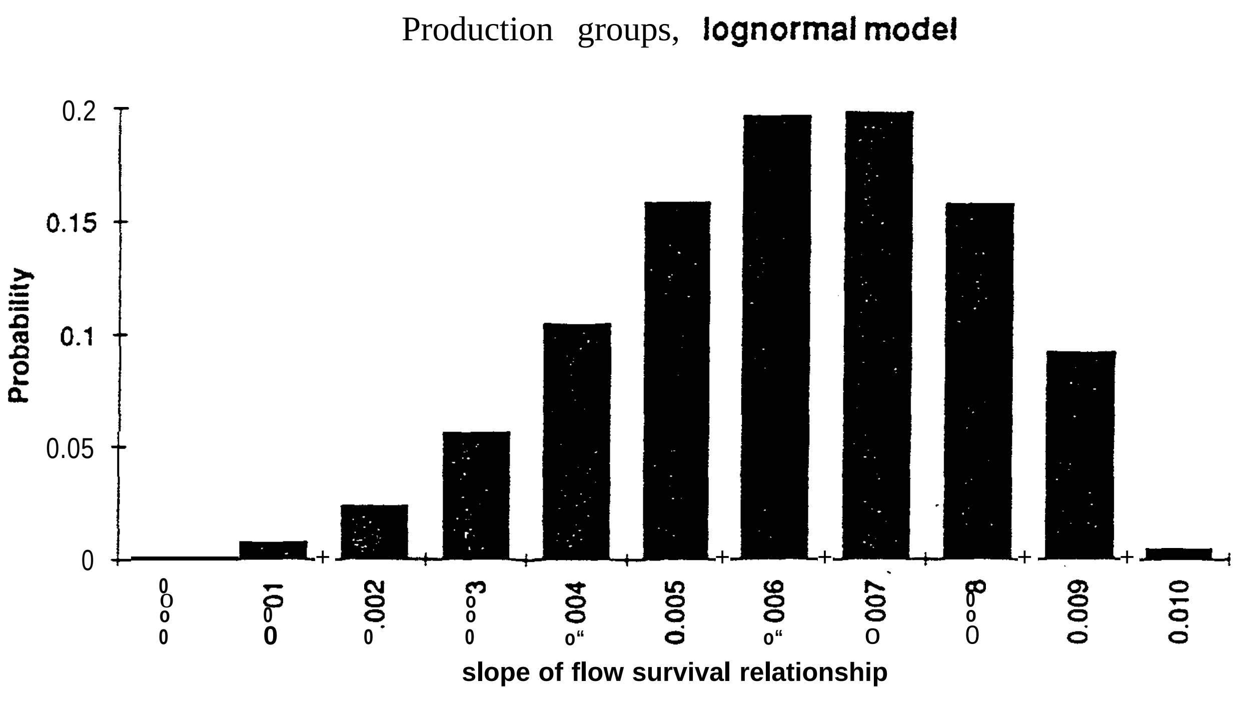

Figure 8. The Bayes posterior distribution for the slope of the flow survival relationship obtained by regression flow on survival.

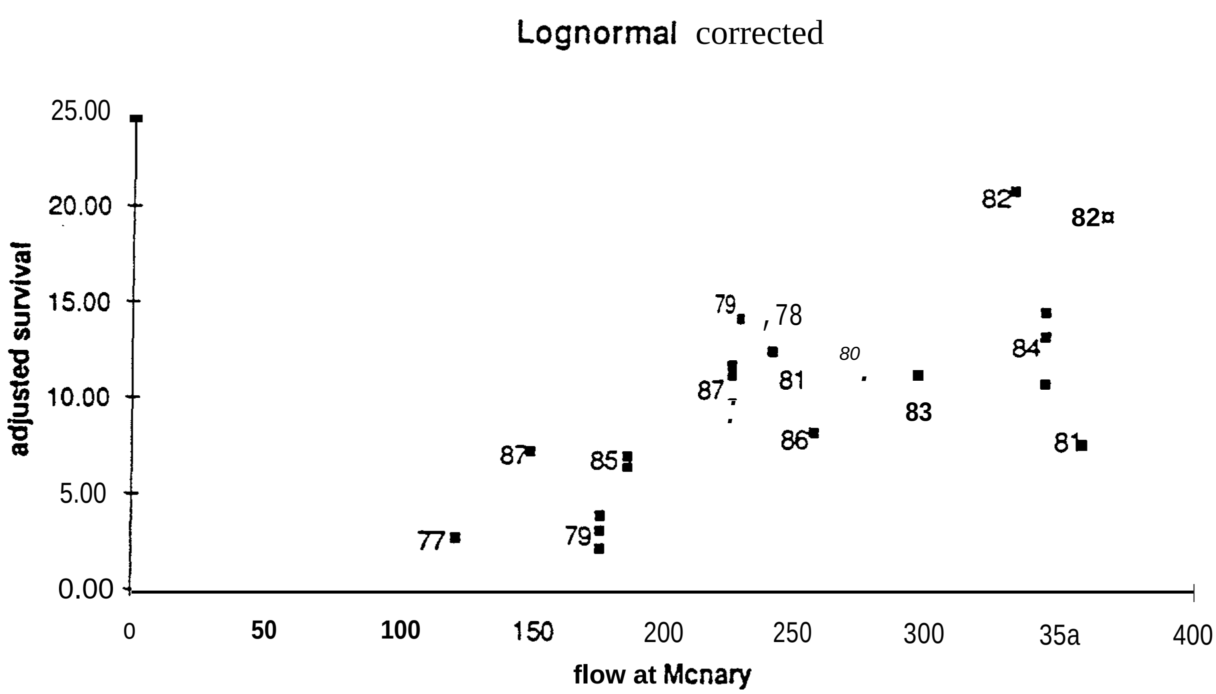

Figure 9. Survival corrected by year and month effect plotted against flow at McNary darn during month of release for CWT groups from Priest Rapids hatchery.

Table 1. Correlation between monthly average flow at McNary dam. 1976-1988.

	Mav	June	Julv	August
May	1.00			
June	0.76	1.00		
July	0.82	0.92	1.00	
August	0.76	0.70	0.85	1.00

Table 2. Cluster analysis results for ocean distribution analysis with the affinities measured against the Priest Rapids stock. Calculations are based on the euclid measure.

Hatchery name	Distance measure	Years of data	Notes
Used in the analysis			
Priest Rapids	N/A	14	
Bonneville	0.0908	14	
Cowlitz	0.1426	14	
Grays River	0.1463	12	
Washougal	0.1136	13	
Not used in the analysis			
Spring Creek	0.2474	17	Small affinity
Lewis River	0.0974	6	Too few years of data
Rock Creek Net Pens	0.1030	1	Too few years of data
Klickitat	0.1485	8	Above Bonneville
Lower Granite	0.1336	1	Too few years of data
Tuttle Rock Net Pens	0.1433	7	Above Bonneville
Irrigon	0.1158	7	Too few years of data
Bonifer Pond	0.1334	1	Too few years of data
Social Security Net Pens	0.0940	1	Too few years of data

Table 3. Analysis of deviance results for poisson error model.

Model Number	Main Effects	Deviance	Df	Scale Factor	Scaled Deviance	Factor Tested	deltascaled deviance	delta df	p value
1	G+Y+H+M+F	892.00	51	17.49	51.00	F	9.74	1	0.0018
2	G+Y+H+M	1062.41	52	17.49	60.74	M	33.23	3	0.0000
3	G+Y+H	1643.55	55	17.49	93.97	H	-119.84	4	0.0000
4	G+Y	3739.50	59	17.49	213.81	Y	491.86	10	0.0000
5	G	12342.15	69	17.49	705.66				

Table 4. Parameters estimated from full model, poisson error, non-experimental codes.

Hatchery (H)		Release Year (Y)		Month (M)	
Bonneville	1.00	1977	1.00	May	1.00
Cowlitz	1.78	1978	0.28	June	0.58
Grays	0.57	1979	0.24	July	0.34
Priest Rapids	2.54	1980	0.28	August	0.62
Washougal	2.44	1981	0.36		
		1982	0.31		
		1983	0.31		
		1984	1.06		
		1985	1.58		
		1986	0.31		
		1987	0.14		
Grand Mean (G)	0.018		Flow slope (a)	.0030	

Table 5. Negative log likelihoods for lognormal error model.

Source	negative log likelihood
Grandmean	227.89
Year	101.23
Hatchery	48.61
Month	41.41
flow	35.00

Table 6. Parameters estimated for lognormal error, full model, non-experimental codes.

Hatchery (H)		Release Year (Y)		Month (M)	
Bonneville	1.00	1977	1.00	May	1.00
Cowlitz	2.39	1978	0.14	June	0.62
Grays	0.93	1979	0.14	July	0.41
Priest Rapids	3.35	1980	0.22	August	0.43
Washougal	3.20	1981	0.31		
		1982	0.14		
		1983	0.23		
		1984	0.72		
		1985	1.22		
		1986	0.25		
		1987	0.12		
'GrandMean	0.016		Flow slope (a)	.0065	

Table 7. Negative log likelihoods for all production and experimental groups

Source	Negative log likelihood
Grandmean	320.68
Year	184.14
Hatchery	169.19
Month	120.91
Flow	113.50

Table 8. Results when using observed recoveries

Model	Negative log likelihood
GrandMean+Year+ Hatchery+Month	38.86
+Flow	35.00
σ	0.42
Flow Slope	.0060

Table 9. Analysis of deviance for model of marine recoveries, aggregated by year and state.

Model	Main Effects	Interactions	Deviance	df	Scale Factor	Scaled deviance	Factor Tested	delta scaled deviance	delta df	p value
1	G+Y+H+M+L+A+F	HA+HL	2001.60	529	3.78	529.00	F	11.71	1	0.0006
2	G+Y+H+M+L+A	HA+HL	2045.90	530	3.78	540.71	HL	232.71	15	0.0000
3	G+ Y+ H+ M+L+A	H A	2926.40	545	3.78	773.41	HA	143.14	15	0.0000
4	G+Y+H+M+L+A		3468.00	560	3.78	916.55	A	502.94	4	0.0000
5	G+ Y+ H+M+L		5371.00	564	3.78	1419.49	L	280.75	4	0.0000
6	G+Y+H+M		6433.30	568	3.78	1700.25	M	109.31	3	0.0000
7	G+Y+H		6846.90	571	3.78	1809.56	H	39.14	4	0.0000
8	G+Y		6995.00	575	3.78	1848.70	Y	382.43	10	0.0000
9	G		8442.00	585	3.78	2231.12				

Table 10. Parameters estimated for model of marine recoveries, aggregated by year and state.

Affect	GLM estimate	GLM s.d.	Multiplicative value
1978	-1.35	0.082	0.26
1979	-1.29	0.093	0.28
1980	-1,28	0.075	0.28
1981	-1.43	0,081	0,24
1982	-1.72	0.099	0.18
1983	-2.00	0.103	0.14
1984	-0.45	0.084	0.64
1985	-0.33	0.066	0.72
1986	-1.78	0.095	0.17
1987	-2.19	0.081	0.11
Cowlitz	0.85	1.258	2.33
Grays	0.74	0.521	2.09
Priest Rapids	0.50	1.095	1.64
Washougal	1,57	1.149	4.81
June	-0.84	0.057	0.43
July	-1.52	0.091	0.22
August	4.02	0.426	0.98
Oregon	1.64	1.017	5.15
Washington	2.75	1.005	15.56
B.C.	3.49	1.004	32.72
Alaska	2.76	1.007	15.77
Age 3	2.15	0.202	8.62
Age 4	1.48	0.209	4,40
Age 5	1.71	0.238	5.53
Age 6	-0.99	0.493	0.37
Flow slope	0.002594	0.00039	1.0026

Appendix B1: Peer Reviews of Hilborn et al. (1993b)

Review comments submitted on behalf of the initial manuscript "The relationship between river flow and survival for Columbia River chinook salmon," authored by R. Hilborn, R. Donnelly, M. Pascual, and C. Coronado-Hernandez (1993 b). General comments tended to be similar and consistent, so a summary was compiled and answered in Appendix B2.

Comments from the following people can be found in the order:

	Name (Organization)	Number of pages
a.	Chris Ross (National Marine Fisheries Service)	6
b.	Al Giorgi (Don Chapman, Assoc. Inc.)	4
c.	John Stevenson (Pacific Northwest Utilities Conference Committee)	6
d.	John Williams, et. al. (National Marine Fisheries Service)	8
e.	Phil Mundy (Columbia River Inter-Tribal Fish Commission)	6
f.	Scientific Review Group; L. Calvin, et al. (Columbia Basin Fish& Wildlife Authority	7

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

12/30/93
D.M.

To : Bob D.

From: Chris Ross

Data show that the primary migration timing of subyearlings at MCN is mid-June → Mid-July, even in 1982 & 87 w/ PRapids releases in May. In 1991 & 92, PRapids fish were at MCN late June → mid-July.

Comment: Consider using flows from mid-June → mid-July. The correlation may not change, but the x-axis values will, i.e., interpretation and use of the relationship may be more accurate w/ the mid-June → mid-July flows.

Happy New Year

Chris

TRANSMITTAL FORM CD-82A (10-67)
PRESCRIBED BY DAO 214-2
☆ U.S.GPO:1983-0-664-006/6040

Bob - This is the rough cut/ for late June releases. we discussed using ave. July flows at MCN, June - July ave. for mid - June releases, ~~and~~ May ave. for early May releases and May - June ave. for mid - May " . I think you're right about not using May 'cause the fish probably don't migrate ~~[illegible]~~ then anyway.

Would appreciate a draft of your final as soon as you have it (so we don't have to wait for printing) - THANKS!

Chris Ross
NOAA/NMFS

911 NE 11
#620
Portland
97232

Lognormal corrected

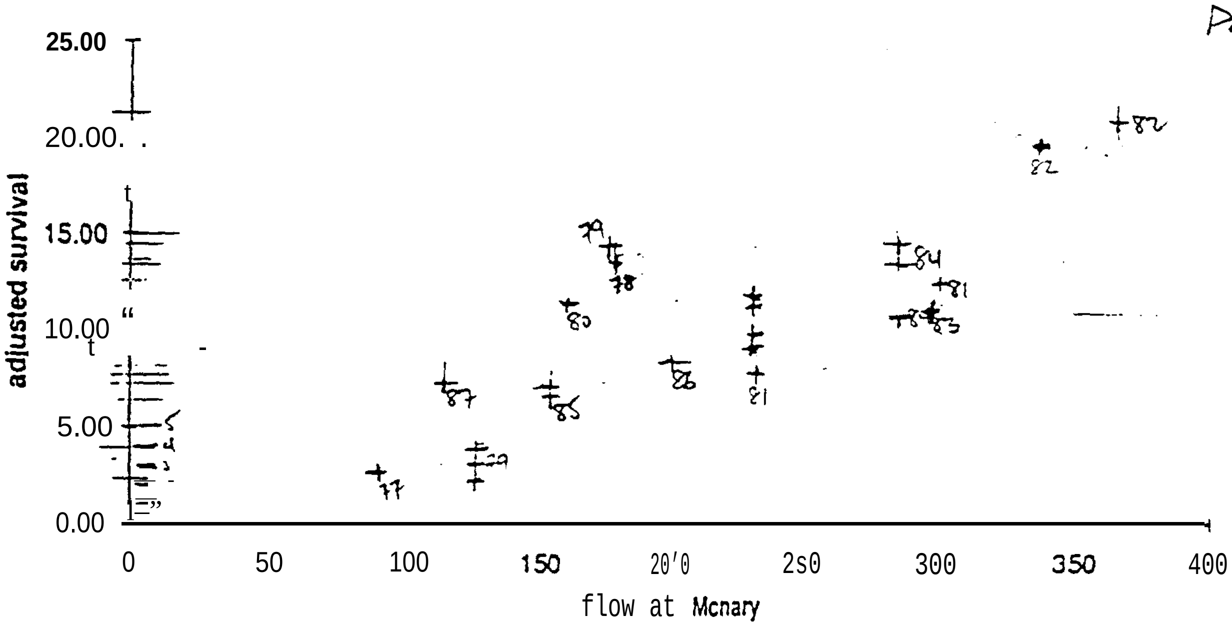

Figure 9. Survival corrected by year and month effect plotted against flow at McNary darn during month of release for CWT groups from Priest Rapids hatchery.

Introduction

Columbia River salmon have been fished for perhaps thousands of years. With the arrival of western European settlers the magnitude of the exploitation increased dramatically. At its peak, the Columbia River salmon stocks produced catches of over 6 million fish from 5 species (Chapman 1986). The peak catches for each species occurred at different times over a period of about 30 years centered around 1900. Chapman (1986) estimated that total return to the Columbia River. catch and escapement, was in the neighborhood of 7.5 million fish. The five species of salmonids native to the Columbia River are chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), socke-- salmon (O. *nerka*), coho salmon (O. *kisutch*), and steelhead trout (*O. masu*) O. mykiss Chinook salmon are recognized as having two distinct life histories, ocean and stream. When *discussing* Columbia River chinook, fisheries managers commonly refer to three races based on time of the return migration: spring; summer, and fall. Spring chinook have a stream-type life history, fall chinook have an ocean-type history, and the summer stocks are a mixture or the two. After emergence. stream-type juveniles generally spend one year in fresh water, usually ~~generally~~ in a tributary stream, before migrating to sea, and are known as "yearlings". Ocean-type juveniles, termed "sub-yearlings", out migrate ~~at the end of~~ during the first summer.

Beginning about the turn of the century, catches began to show a downward trend although the annual fluctuations continued. The adults that migrate into the river during the summer have suffered the most (Thompson 1951), declining to very low numbers, recovering slightly in 1959 and then declining again (Chapman 1986). Most authorities (e.g. Laythe et al. 1948, NWPPC. 1986) have attributed the decline in chinook runs to a wide variety of causes including deforestation, farming, mining, pollution, over-fishing, unscreened water diversions and construction of dams - the last considered to be the major contributor. To overcome these problems, Laythe (1948) suggested a mitigation program in the lower river which included screening, water diversions, and habitat protection, as well as the construction of fish hatcheries. The hatcheries and lower-river efforts were never fully implemented, and b y the mid- 1970's the runs of chinook salmon - to the mid-Columbia were at extremely low levels. The use of hatcheries to increase the upriver runs had proved relatively unsuccessful

Studies were initiated on the surviving chinook salmon stocks in the mid-Columbia River from Bonneville Dam to "Grand Coulee Dam. Raymond (1969, 1979, 1988) studied the effect the dams were having on travel time of the out migrant smolts. Two major findings from his work were (i) wild stocks had better survival compared to hatchery stocks, and (ii) impoundment of water behind the dams slowed out migration and were thought to reduce survival. The direct effect of river discharge on downstream movement of salmon fry has been studied by a number of investigators (Irvine 1986; Giorgi et al. 1990; Raymond 1968; Park 1969: Stevenson and Olsen 1991) with varying results. Giorgi et al. (1990) investigated the relation of flow to travel time of sub-yearling chinook salmon and were unable to conclude that changes in flow were related to changes in travel time; however they did note that fish moving out in the early part of the summer had higher yearling

survival to adulthood compared with those that out migrated later. Raymond (1969) found that the John Day Reservoir increased the travel rime of out migran smolts from 14 days to 22 days for that stretch of river. Stevenson and Olsen (1991), experimenting with different flow regimes in John Day Reservoir, were unable to demonstrate a solid relationship between flow and travel time. Park (1969) concluded that. with the advent of dams, the peak flo ws were reduced, turbidity was decreased, predation and disease increased, and that "an almost continuously impounded river, with resultant trends toward warming water and increased numbers of predators, and other complex changes in the environment, could eventually jeopardize the existence of the chinook salmon in the [mid] Columbia River."

There is little question that the downriver movement of the juvenile salmon has been slowed by the construction of darns (Raymond 1979; Ebel and Raymond 1976). For each dam constructed above Ice Harbor darn on the Snake River. the travel time was increased by about 50% or more (Ebel and Raymond 1976), or an average delay of 8 davs per reservoir. Raymond found that migration rates for juveniles were on the order of 40 to 5S km/day for both free flowing and impounded stretches at moderate river flows (about 8,500 m^3/sec.), and in the range of 24 to 27 km/day at iow flows (about 42S0 m^3/sec.).

Hatchery fi data (FPC show 10- travel tim from LWG MCN ≅ 3 ~ %

While the hypothesis that flow and travel rime are inversely related is viewed as a basis for present river management, the situation is not as clear as might be hoped - apparently confused by confounding variables. For example, travel time is related to the condition of the juveniles at time of migration. Their physiological condition is related to water temperature which in turn is related to the time of year (Giorgi et al. 1988). The later in the year, the faster the juveniles appear to migrate (Chapman et al. 1991).

In an effort to shed light on a complex situation and to prevent continuing erosion of Columbia River salmon runs, Congress passed the Pacific Northwest Electric Power Planning and Conservation Act in 1980 which authorized the states of Idaho, Montana, Oregon and Washington to create a entity to plan for two important resources in the Columbia River basin: electricity, and fish and wildlife. The entity created was the Pacific Northwest Electric Power and Conservation Planning Council, best known as the Northwest Power Planning Council. To emphasize the importance of fish and wildlife. Congress mandated that the Council develop the Columbia River Basin Fish and Wildlife Program before developing a power plan.

The Council has established the doubling of the salmonid runs of the Columbia River as a primary goal of its Fish and wildlife Program. Achievement of this objective could result from: (i) an increase in the production of hatchery salmon, (ii) increases in the production of natural spawning salmon. and (iii) increase in the downstream survival of juveniles. All three factors are likely to be involved in a truly successful stock rebuilding effort. *Many* management actions have been taken in an attempt to increase downstream survival, including: (i) fish bypass facilities: screens that divert juvenile salmon from the turbines, passing them through the dam in a separate water system, (ii) transportation: juvenile salmon collected at the fish bypass facilities and transported via

(iv) decrease in harvest 7

Flow augment separate from spill.

#

(iv) increasing augmenting

barge below Bonneville Dam where they are released; (iii) increased flow during periods of smolt migration; ~~augmenting~~ the spill of water over the dam bypassing the turbines; (v) predator control: reducing the population of northern squawfish (*Ptychocheilus oregonensis*) in the reservoirs. Each of these actions is directed toward increasing the survival of juvenile fish ~~from the time of release until they enter the lower river below Bonneville Dam.~~ through out the hydroelectric system. While fish bypass facilities have been evaluated using fin-clipped or freeze-branded fish, and transportation evaluated using coded-wire-tags, to date no attempts have been made to evaluate increased flow or predator control efforts.

?? Annual ... have Sims & O., 19.. etc Petrosky 1991.

One of the guiding principles of the Fish and Wildlife Program is adaptive management - learning by past actions. Until managers are able to evaluate reliably the effectiveness of their actions; learning will be slow. Changes in flow and other factors associated with downstream survivals to some extent can be evaluated by in-river mark recap cure experiments, and such experiments arc certainly an essential part of any well-designed attempt to evaluate water flow. However. this is not practical on a big enough scale to encompass all hatchery stocks, nor would such an in-river mark recovery program measure impacts that might occur once the fish leave the river.

Unclear. ~~Hard to~~ ~~influence~~ ~~the~~ ~~salmonid~~ ~~survival~~. study ongoing.

Most studies of the relationship between flow & survival have concentrated on in-river measurements and comparison, primarily using freeze branding ~~to measure travel-times.~~ Such studies have no way of examining the impact of changes in flow on survival after the fish pass through the dam system. A potential source of such data is the coded wire tag (CWT) data base. Since the early 1970s, thousands of groups of hatchery and wild fish have been tagged *on the* Columbia, and the commercial and recreational fisheries and escapements to hatcheries have been systematically sampled to obtain tag recoveries. CWT data have been routinely used by the Pacific Salmon Commission (PSC) working groups to estimate survival of Columbia River stocks.

The purpose of this study is to investigate the potential for using the CWT data base to examine the relationship between in-river factors (especially flow) and survival ~~in~~ of Columbia River chinook salmon.

Methods and Results

Estimating Survival from Coded-Wire-Tag data

Since the early 1970's approximately 2600 individual groups of chinook salmon have been marked with CWT's on the Columbia River. These rags have been applied primarily at hatcheries, although there has been some marking of wild stocks, and some of fish collected at ti. The motivation for tagging has been quite diverse, but most tags have been applied to compare experimental hatchery treatments, such as size and time of release, feeding regimes, or other hatchery practices. The data base on CWT data denotes three primarily types of tagging, experimental. production and index. Experimental tag groups are those mentioned previously, where agencies arc experimenting with hatchery practices in some way. Production groups arc fish reared under normal hatchery conditions and tagging is done in order to determine the . contribution of the bulk of the hatcheries release to fisheries and return to escapement. Index tag codes are specifically designated for use in evaluation of fishery management practice.

For the purposes of examining the impact of in-river conditions on survival, the production and index tag codes are preferable because they have not been subjected to any experimental treatments. However, many experimental groups appear to have similar survival to the hatchery production groups, and since far more releases are experimental than either production or index, we may not want to exclude experimental groups out of hand.

Since the aim of this project is to examine the relationship between in-river flow and the subsequent survival, we must have CWT groups released from a range of flow conditions.. Figure 1 shows the average flow at McNary darn in May. from 1976 to 1989. The amount of variation in flow is not great, but there is a little more than two times variation from the lowest year, 1977 with a flow of 150,000 cfs, to the highest year 1976 with an average flow of 350,000 cfs.

Figure 1 near hero

The highest flows occur in May and June. with declining flows in July and August. Figure 2 shows the seasonal pattern of flow for 1976 to 1988. There is a high correlation in flows between months (Table 1), generally 0.8 or higher.

Figure 2 near here
Table 1 near here

We searched over all available CWT codes for hatcheries that met two conditions, (1) the hatchery must be upstream of McNary dam so that the juveniles had to pass through the four lower river dams at a minimum, and (2) there must have been non-experimental tagging over a number of years with contrast in flow.

Unfortunately, only Priest Rapids hatchery met these conditions. None of the *Snake River* hatcheries had consistent enough tagging to provide a usable base of data, and none of the other hatcheries on the mainstem above McNary dam had more than occasional tagging. 'Priest Rapids. in comparison, had consistent production or index tagging from brood year 1975 to the present time. Only three of the tag groups at Priest Rapids hatchery were experimental. In recent years a number of other hatcheries have begun systematic tagging of index or production groups, and within 5 or 10" years there will be a much bigger base of available hatcheries. However, at present, only Priest Rapids hatchery provides enough tag groups over enough years to examine the relationship between flow and survival.

For any CWT group, we can estimate the survival from release to any arbitrary age using the method of Virtual Population Analysis (VPA). This method is routinely used for chinook salmon by the Chinook Technical committee (CTC) of the Pacific Salmon Commission (PSC), and the method is described in Hilborn and Wakers (1992). Because

Memorandum

4 Oct., 1993

To: Bob Donnelly, UW
From: Al Giorgi, DCC
Subject: Review of draft CWT manuscript

On page 5, the stated purpose of the study was to investigate inriver factors (especially flow) and survival in Columbia River chinook salmon. But in fact, only a single factor, flow, was examined. In my view this is a major shortcoming of the analysis. Since all of your analytical models indicate a relationship between flow and survival to age two, further development and treatment of the mechanisms that could affect survival and accompany increasing flows is warranted. Flow is only a general index of overall passage conditions. At high flow levels, spillage increases. This would be expected to enhance mainstem survival. Some investigations indicate that subyearlings migrate faster with increasing flows, which may increase survival to some degree. You fail to either discuss, or analytically treat these matters. Your results and discussion sections imply that increased flow increases survival, but it is possible to provide spill at any flow level. Which mechanism is really key in improving survival? There may be others as well, such as those you briefly identify in the discussion section such as the potential for estuarine conditions to fluctuate with flow volume.

Since spill and fish migration speed are repeatedly implicated as mechanisms affecting instream survival, you should at least treat these. For example, in Figure 9; 1977, 1979, 1985, 1987 yielded the lowest adjusted survival. Your depiction illustrates that your index flows were below 200 kcfs. However, in those same years spill was either absent or negligible during the June/July/August period, when these fish are migrating seaward. The problem is that spill effects cannot be separated from perceived migration effects in these data sets. You must inform the reader of this difficulty. If you do not, you may spawn yet another Sims and Ossiander debate. Some readers will see flow as a surrogate for migration speed related survival effects, while others will contend it is a spill effect. You could illustrate the difficulty by showing the correlation between spill and flow in this data set, and discussing the ramifications.

Temperature is another important factor that affects predatory fish consumption rates. Int he lower Columbia there may be a relation between your flow index and temperature. This should be explored. Giorgi et al. (1990) showed that throughout the summer, survival to adult decreased, for three years. Over the course of each summer flows decreased, spill % decreased, and temperature increased. All highly correlated. It was impossible to attributes effects to any single variable. They probably work in concert.

Transportation: The proportion of the Priest Rapids population subjected to transportation each year will affect survival. Estimating this will be difficult. Prevailing spill levels at the time the population passes McNary is critical, as might be annual changes in FGE, which in themselves may be flow sensitive. Some creative thinking may lead to some plausible index.

In summary, this is a multivariate river system, analyses must treat it as such. I would be willing to work with you in devising appropriate indices of spill, temperature and transportation. There may even be some travel time data from hatchery to MCN and John Day that be instructive. Branded groups were released from PR in some years.

Some Specific Questions/Items:

The Flow index:

I suggest selecting a flow index other than month of release. Freeze brand data for this population indicates the median passage time at McNary Dam to be the very end of June and through early July. The bulk of the population is moving through the lower impounded section primarily during July. This would appear to be a preferable index period, when attempting to -characterizes inriver conditions during migration. Alternatively, averaging flows over 'a thirty-day period following release may be useful since the median travel time to McNary dam is typically near 20 days (see some FPC reports since 1983) . Either of these seem preferable to the current index. For example, many groups are released during the last ten days of May or "June, and are not even inriver during the majority of the period you have selected as the index(i.e. month of release) .

Tule stocks as control groups for Priest URBs:

Except for URBs at Bonneville hatchery, the rest of the control populations appear to be tule stock. It seems like it would be difficult to argue that tules and URB are similar enough to warrant use as controls. Ocean distribution is only one indicator of similarity. Perhaps other life history traits need examination. To dismiss this as a concern seems most inappropriate, and will certainly be subject to criticism in any final draft.

Survival estimates:

In the results section it is not apparent which hatchery populations were used as controls to yield figure 9. Were hatcheries pooled in some years. The mechanics of the procedure is not clear. Also, is the adjusted survival in figure 9 survival to age 2? Then the survival in figure 7 is survival to returning adult?

Assumptions:

Equation #1 assumes that the P's are known. P's are estimated and never "known". How robust is the analysis to 'departures from estimated P? Discussion of this seems appropriate. Also, the cited P values from the CTC are for what race of chinook; presumably they are falls, not spring chinook. Please clarify. Also, the CTC values are reported without error. What are the variances associated with these estimates, and how does that affect analyses and conclusions?

Inter-dam loss of fish appears to be ignored in these analyses. It is not clear that this is warranted. Priest Rapids fish incur this mortality, while control stocks do not. It seems that some adjustment is required.

Hypothesis testing:

On page 7 you state that hypothesis testing is inappropriate for decision making. Yet on page 13 you test models which pose hypotheses? What's up?

Discussion:

The range of the change in survival related to flow ranged from 26 to 65 %, not. the 20 and 60% specified on p. 18.

Yogi state that flow affects estuarine conditions; how so? A little discussion of estuarine dynamics seems in order.

The big one - what mechanisms associated with, or accompanying increased river discharge are implicated as affecting survival. The paper conspicuously avoids any treatment of migration speed, temperature/predation dynamics, spill volumes, or transportation. The analyses and discussion are in my view incomplete in this regard. Further analyses are warranted.

cc: Pat Poe

PNUCC

PACIFIC NORTHWEST UTILITIES CONFERENCE COMMITTEE

December 13, 1993

Mr. Robert Donnelly
School of Fisheries WH-10
University of Washington
Seattle, Washington 98195

Dear Mr. Donnelly:

I, along with PNUCC member biologists and other PNUCC staff biologists. have reviewed the manuscript entitled "T'he relationship between river flow and survival for Columbia River chinook salmon, 'f and offer the following comments.

General Comments

Abstract – The abstract of the manuscript states:

> *The relationship between flow* and *survival when corrected for ocean condition shows a stronger correlation, which is highly significant. The slope indicates that an increase in flow of 100,000 cfs at McNary Dam would result in 65 percent increase in survival of Priest Rapids hatchery fish.*

Although this conclusion is discussed within the body of the text, it leads the reader to believe that this is the major conclusion of the paper. Later in the text, a statement is made to the effect that while it appears that survival is correlated to flow, you do not feel confident in saying which statistical model most accurately reflects that relationship. You continue by saying that you are less confident in the expected increase of survival in relation to flow than you are with which model to use. Despite these statements, you present the results of the Virtual Population Analysis and conclude that a flow increase of 100 kcfs at McNary will result in a survival increase of *65* percent for Priest Rapids hatchery fish. My concern is that many people will read only the abstract and will miss the main conclusion of your paper, which 1 read as-flow is correlated to survival, but to what extent you are uncertain. I strongly suggest that you edit your abstract to more accurately reflect the contents of your paper. To do otherwise would be negligent.

In addition, the objective of your work should be clearly identified within the abstract. As stated on pa; 5, the objective is to ". . . investigate the potential for using the CWT data base to examine relationship between in river factors (especially flow) and survival in Columbia River chinook salmc In line with this objective, your conclusions should address the utility of these coded wire tag da evaluating survival, and of the paper's statistical modeling methods for analyzing the data to dete the correlation between flow and survival. You should also point out that your work is of experimental nature in that you have not evaluated CWT data in comparison with other data (suc' PIT tag data collected in 1993 in the Snake River).

Mr. Robert Donnelly
December 13, 1993
Page 2

Assumptions - In each of the statistical analyses you have presented, there are several key assumptions that have not been fully considered (e.g., transportation, spill, inter-dam loss, mortality due to elevated nitrogen levels). Although these assumptions are acknowledged, you have not adequately addressed them in your analysis. For example, adult in-river mortality between Bonneville and McNary dams has ranged from 0.7 percent in 1986 to 22.3 percent in 1991, and has averaged 15.1 percent from 1986 to 1992. Because each variable is affected by flow, and subsequently affects survival, it is important to address each of them within your analysis.

Other Factors - Assuming that temperature is significantly correlated to time, time to flow, and flow to survival, is it possib le the affects on survival seen in the analysis are in part the result of temperature? Also, is the possible influence of temperature on survival addressed adequately by evaluating the variable "month effect"? Knowing that temperature is a function of time, and there is a correlation between flow and time, I wonder how much of the correlation between flow and survival may be explained by increasing temperatures. This may be an issue considering the propensity of fall chinook to rear within the river prior to migration. Also, given the fact that Priest Rapids fall chinook are typically released late in the season when temperatures are high, predation is high, and the smelts are relatively small (in 1993, PRD fish were released at 50-70 fish/pound in June).

Control Group - Your analysis is based on the assumption that lower river and Priest Rapids hatchery groups have comparable ocean mortality rates. I would argue that this may not be the case. The stock used as your treatment group is an up-river bright population, whereas the lower river control groups are of Tule origin. Based on data produced by the Pacific Salmon Commission Joint Chinook Technical Committee in their 1991 Annual Report, the attached tables show how catch distribution and total harvest mortality varies between the up-river bright and tule stocks. In addition to the differences in distributions between the stocks, fisheries management has also varied from year to year for each of the fisheries listed in the tables. The variation in distribution and changes in harvest management could account for the differences in survival observed for each stock. Furthermore, different ocean environmental conditions can affect the survival of each stock due to the differences in ocean distribution.

It may also be useful to address how the treatment group compares to wild Hanford Reach fall chinook with regard to migrational timing to McNary Dam. If peak timing for both stocks is not fairly close, conclusions drawn for hatchery fish may not apply to wild stocks due to the time-sensitive effects of a multitude of variables.

I appreciate the opportunity to comment on your draft manuscript, and would be more than happy to discuss these comments with you. If you have questions, I may be reached at (503) 223-9343.

Sincerely,

John R. Stevenson "
Senior Fisheries Analyst

cc: Patrick Poe, Bonneville Power Administration

Mr. Robert Donnelly
December 13, 1993
Page 3

Annual distribution of reported catch (PSC TCCHINOOK (92)-4).

Stock	All Alaska	All Nth/Cnt BC	Fisheries WCVI Troll	Total Geo St	Other Canada Net	Other Canada Troll	Other US. Troll	Other US. Net	Other US. sport
URB (79-91)	26.0	19.2	13.3	0.3	0.9	0.2	1.9	34.4	3.9
Cowlitz (81-91)	6.9	9.7	21.8	0.2	2.0	0.7	17.9	20.2	20.6
Bonne-ville (80-87)	**0.0**	3.4	37.3	2.4	4.6	1.9	14.0	19.6	16.9
Spring Creek (79-91)	**0.0**	0.9	25.4	1.2	1.2	0.9	19.8	36.9	13.8

Annual distribution of total mortalities (PSC TCCHINOOK (92)-4).

Stock	Ail Alaska	All Nth/Cnt BC	Fisheries WCVI Troll	Total Geo St	Other Canada Net	Other Canada Troll	Other US. Troll	Other US. Net	Other US. sport
URB (79-91)	30.8	18.5	13.0	0.3	0.7	0.1	1.9	31.1	3.5
Cowlitz (81-91)	9.1	9.7	22.3	0.2	1.8	0.6	18.4	[redacted]	19.2
Bonne-vine (80-87)	0.0	3.0	39.6	1.8	3.0	1.2	[redacted]	[redacted]	[redacted]
Spring Creek (79-91)	**0.0**	0.9	25.8	1.1	i.0	0.9	20.6	35.0	14.7

Reproduced from tables presented in the Pacific Salmon Commission Joint Chinook Technical Committee 1991 Annual Report.

Mr. Robert Donnelly
December 13, 1993
Page 4

Specific *Comments*

Page	Par	Line	Comment
2	Abstract		Should list all of the factors evaluated in the analysis, not just flow.
2	Abstract		A summary within the abstract on the range of slopes developed in the analysis, their significance, and a statement of the assumptions would be very useful.
2	Abstract		Instead of stating ". . . long time series of coded wire tag (CWT) release groups. . . " it may be more accurate to state "a series of coded wire tag (CWT) release groups over an extended time period. " "Time series" may be confusing to the reader since it implies that a time series analysis was performed.
3	1	3	Is this saying that an "annual" harvest rate for the five species was in the neighborhood of 6 million fish, or that over the 30 year period the total catch was 6 million? This needs to be more specific.
	1	7	Should change "The five species of salmonids native to . ." to "The five species of *anadromous* salmonids native to . . . ." Also, should other anadromous salmonids be added to this list such as sea-run cutthroat trout and dolly varden?
	1	9	The scientific name for steelhead is incorrectly referenced as *Onchorhynchus maw.* The correct reference is O. *mykiss*. O. *masou* is a salmonid species commonly referred to as the masu salmon, and is only found in Asia.
	3	2	Change "Grand Coolee Dam" to "Grand Coulee Dam. "
	5	2-5	I would agree that each of the measures identified possess the potential to aid in the achievement of the Council's goal. But, while although the focus of your paper is on downstream migration, and more specificall y survival, I would include other life stages where survival may be increased to improve adult contribution (e. g., improved estuarine and ocean survival, . decreased exploitation, improved adult instream survival, etc.). "

Mr. Robert Donnelly
December 13, 1993
Page 5

Specific Comments

Page	Par	Line	Comment
5	1	1	Item (ii), which begins on page 4 should be modified to reflect that fish are also transported by truck, not just barge.
5	1	5	*The* statement ". . . survival of fish from the time of release until they enter . . ." implies that these measures are intended for hatchery fish alone. The insertion of "or emergence" after "release" would make the statement more accurate.
5		6-8	In the last sentence of this paragraph, two points are made. First, that in-river mark recapture studies are not able to evaluate in-river survival on a large scale. Second, that in-river mark recapture studies cannot identify mortality after a fish has left the river system. I would disagree that mark recapture cannot evaluate hatchery stock survival. Using the single release method tested by the National Marine Fisheries Service in 1993, I would think that with enough PIT-tagged hatchery fish, survival could indeed be measured. I would agree that mark recapture methods cannot evaluate mortality once a fish leaves the river system. But that is only an issue if it is assumed that the effects of mortality are realized after the fish has left the system. I am not aware of any empirical data to support this theory.
	2 *(full)*	4-6	In the analysis, the test and control fish were of upriver-bright and tule stock respectively. Because of the difference in ocean migrational patterns, the argument can't be made that both test and control fish are exposed to the same incidental fishing mortality.
11	1	4	Need to correct the statement ". . . among fish released in 1985 and 1985 . . . ."

Mr. Robert Donnelly
December 15, 1993
Page 6

Specific comments

Page	Par	Line	Comment
11	Equation 9		Flow is not independent of year and month. Some discussion of how this is accounted for (if it is) would be helpful. The problems with using average flow during the month of release should be discussed. Also, separation of temperature effect from the flow effect would make the model more accurate.
12	3 (full)	6	Capitalize “spring creek. ”
12	3 (full)	10-11	What is the source of the ocean spatial distributions presented in figure 6?
12	3 (full)	11	Capitalize “priest. ”
13	3 (full)	1	Should “defiance” be “deviance”?
13	3 (full)	2	Should “equation x“ be “equation 9“?
14	Equation 11		One of the M’s on the right hand side of the equation should be sub i, not j.
18	1	2-5	The statement “. . . evidence that higher flows would lead to better survival . . . throughout the entire Columbia and Snake river basins” is at this time conjecture. It should be deleted from the text.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Fisheries Science Center
Coastal Zone and Estuarine Studies Division
2725 Montlake Boulevard East "
Seattle, Washington 98112-2097

November 16, 1993

Dr. Robert Donnelly
School of Fisheries, WH-10
University of Washington
Seattle, Washington 98195

Dear Bob,

Attached are some combined anonymous staff reviews, with comments also added to the text, of the draft report entitled "The relationship between river flow and survival for Columbia River chinook salmon." I hope that you will find them constructive. It appears that one of the largest problems may lie with the ocean distributions of the lower river versus Priest Rapids Hatchery fish. Maybe a more prominent placement of the caveats outlined by one reviewer would also improve the strength of the paper (but not necessarily of the conclusions found) . If you have any questions, give me a call at 860-3277.

Sincerely yours,

John G. Williams

cc: Pat Poe

Hillborn et al. 1993

Editorial comments:

Generally sloppy writing.

Page 3, para 1: masu should be mvkiss.

Page 5, para 1: "to date no attempts have been made to evaluate increased flow for predator control effects (on ' survival)"

Authors should read Sims and Ossiander, Petrosky, etc.

Page 7, para 1:
Calculation of survival to age 2:

Assumes probability of survival from age 2 to age 6 is known, only losses to fishery and escapement, and all fish spawn by age 6.

Does not consider upstream passage mortality. Chose to ignore incidental fishing mortality assuming all groups affected equally.

Page 7, last para:

Why is "hypothesis testing inappropriate for decision-making"?

"It is statistically inappropriate to use survival rates as the y variable in a linear regression."

Pages 8-9:

in arguing against the appropriateness of hypothesis testing for decision-making, the only argument put forward involves hypothesis testing and using survival as the y variable in a linear regression.

Figure 6 apparently indicates an ocean distribution of fish that is substantially different for Priest Rapids fish compared to fish from the lower Columbia River hatcheries. Figure 6 is misleading because it covers up the distribution of fish off the Washington Coast; nonetheless, it appears that approximately 35% of the Priest Rapids fish are caught in Alaska and while only 4% in Washington. In contrast, it appears that Bonneville Hatchery may have the closest distribution to the Priest Rapids stock; however, Bonneville Hatchery fish are caught at 1/2 the rate in Alaska and nearly 6 times the rate in Washington compared to the Priest Rapids fish. From these results, it appears inappropriate to use lower river stocks to adjust for ocean mortalities. This is particularly so since stocks of fish from Alaskan waters have had a substantial increase in survival since the late 1970s (the period you considered here). It seems highly plausible that Priest Rapids fish may have survived at a higher rate than lower river hatchery because of a different ocean distribution. Total stock returns to the Columbia River would appear to bear this out where lower river tules and upper river bright fall chinook seem to ~~have that~~ When one group has high returns, the other does not, and vice versa.

alternate.

Introduction

Columbia River salmon have been fished for perhaps thousands of years. With the arrival of western European settlers the magnitude of the exploitation increased dramatically. At its peak, the Columbia River salmon stocks produced catches of over 6 million fish from 5 species (Chapman 1986). The peak catches for each species occurred at different times over a period of about 30 years centered around 1900. Chapman (1986) estimated that total return to the Columbia River, catch and escapement, was in the neighborhood of 7.5 million fish. The five species of salmonids native to the Columbia River are chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), and steelhead trout (*O. masu*). Chinook salmon are recognized as having two distinct life histories, ocean and stream. When discussing Columbia River chinook, fisheries managers commonly refer to three races based on time of the return migration: spring, summer, and fall. Spring chinook have a stream-type life history, fall chinook have an ocean-type history, and the summer stocks are a mixture of the two. After emergence, stream-type juveniles spend one year in fresh water, ~~generally~~ usually in a tributary stream, before migrating to sea, and are known as "yearlings". Ocean-type juveniles, termed "sub-yearlings", out migrate ~~at the end of~~ during the first summer.

mykiss

Beginning about the turn of the century, catches began to show a downward trend although the annual fluctuations continued. The adults that migrate into the river during the summer have suffered the most (Thompson 1951), declining to very low numbers, recovering slightly in 1959 and then declining again (Chapman 1986). Most authorities (e.g. Laythe et al. 1948, NWPPC. 1986) have attributed the decline in chinook runs to a wide variety of causes including deforestation, farming, mining, pollution, over-fishing, unscreened water diversions and construction of dams - the last considered to be the major contributor. To overcome these problems, Laythe (1948) suggested a mitigation program in the lower river which included screening, water diversions, and habitat protection, as well as the construction of fish hatcheries. The hatcheries and lower-river efforts were never fully implemented, and by the mid- 1970's the runs of chinook salmon to the mid-Columbia were at extremely low levels. The use of hatcheries to increase the runs had proved relatively unsuccessful.

upriver ?

Studies were initiated on the surviving chinook salmon stocks in the mid-Columbia River from Bonneville Dam to Grand Coulee Dam. Raymond (1969, 1979, 1988) studied the effect the dams were having on travel time of the out migrant smolts. Two major findings from his work were (i) wild stocks had better survival compared to hatchery stocks, and (ii) impoundment of water behind the dams slowed out migration and were thought to reduce survival. The direct effect of river discharge on downstream movement of salmon fry has been studied by a number of investigators (Irvine 1986; Giorgi et al. 1990; Raymond 1968; Park 1969; Stevenson and Olsen 1991) with varying results. Giorgi et al. (1990) investigated the relation of flow to travel time of sub-yearling chinook salmon and were unable to conclude that changes in flow were related to changes in travel time; however they did note that fish moving out in the early part of the summer had higher yearling

survival to adulthood compared with those that out migrated later. Raymond (1969) found that the John Day Reservoir increased the travel time of out migrant smolts from 14 days to 22 days for that stretch of river. Stevenson and Olsen (1991), experimenting with different flow regimes in John Day Reservoir, were unable to demonstrate a solid relationship between flow and travel time. Park (1969) concluded that, with the advent of dams, the peak flows were reduced, turbidity was decreased, predation and disease increased, and that "an almost continuously impounded river, with resultant trends toward warming water and increased numbers of predators, and other complex changes in the environment, could eventually jeopardize the existence of the chinook salmon in the [mid] Columbia River."

There is little question that the downriver movement of the juvenile salmon has been slowed by the construction of dams (Raymond 1979; Ebel and Raymond 1976). For each dam constructed above Ice Harbor dam on the Snake River, the travel time was increased by about 50% or more (Ebel and Raymond 1976), or <u>an average delay of 8 days per reservoir.</u> Raymond found that migration rates for juveniles were on the order of 40 to 55 km/day for both free flowing and impounded stretches at moderate river flows (about 8,500 m^3/sec.), and in the range of 24 to 27 km/day at low flows (about 4250 m^3/sec.).

Hatchery data (FPC) shows 10- travel time from LWG ≅ 3 per project at ~100

While the hypothesis that flow and travel time are inversely related is viewed as a basis for present river management, the situation is not as clear as might be hoped - apparently confused by confounding variables. For example, travel time is related to the condition of the juveniles at time of migration. Their physiological condition is related to water temperature which in turn is related to the time of year (Giorgi et al. 1988). The later in the year, the faster the juveniles appear to migrate (Chapman et al. 1991).

In an effort to shed light on a complex situation and to prevent continuing erosion of Columbia River salmon runs, Congress passed the Pacific Northwest Electric Power Planning and Conservation Act in 1980 which authorized the states of Idaho, Montana, Oregon and Washington to create a entity to plan for two important resources in the Columbia River basin: electricity, and fish and wildlife. The entity created was the Pacific Northwest Electric Power and Conservation Planning Council, best known as the Northwest Power Planning Council. To emphasize the importance of fish and wildlife, Congress mandated that the Council develop the Columbia River Basin Fish and Wildlife Program before developing a power plan.

The Council has established the doubling of the salmonid runs of the Columbia River as a primary goal of its Fish and Wildlife Program. Achievement of this objective could result from: (i) an increase in the production of hatchery salmon, (ii) increases in the production of natural spawning salmon, and (iii) increase in the downstream survival of juveniles. All three factors are likely to be involved in a truly successful stock rebuilding effort. Many management actions have been taken in an attempt to increase downstream survival, including: (i) fish bypass facilities: screens that divert juvenile salmon from the turbines, passing them through the dam in a separate water system; (ii) transportation: juvenile salmon collected at the fish bypass facilities and transported via

(iv) decrease in harvest ?

spill.

barge below Bonneville Dam where they are released; (iii) ~~increased~~ augmenting flow during periods of smolt migration; (iv) increasing ~~augmenting~~ the spill of water over the dam bypassing the turbines; (v) predator control: reducing the population of northern squawfish (*Ptychocheilus oregonensis*) in the reservoirs. Each of these actions is directed toward increasing the survival of juvenile fish ~~from the time of release until they enter the lower river below Bonneville Dam.~~ past the hydroelectric system. While fish bypass facilities have been evaluated using fin-clipped or freeze-branded fish, and transportation evaluated using coded-wire-tags, to date no attempts have been made to evaluate increased flow or predator control efforts.

One of the guiding principles of the Fish and Wildlife ~~Plan~~ Program is adaptive management - learning by past actions. Until managers are able to evaluate reliably the effectiveness of their actions, learning will be slow. Changes in flow and other factors associated with downstream survivals ~~to some extent can be evaluated~~ by in-river mark recapture experiments, and such experiments are certainly an essential part of any well-designed attempt to evaluate water flow. However, this is not practical on a big enough scale to encompass all hatchery stocks, nor would such an in-river mark recovery program measure impacts that might occur once the fish leave the river.

Unclear. Study ongoing.

Most studies of the relationship between flow and survival have concentrated on in-river measurements and comparison, primarily using freeze branding ~~to measure travel times.~~ Such studies have no way of examining the impact of changes in flow on survival after the fish pass through the dam system. A potential source of such data is the coded wire tag (CWT) data base. Since the early 1970s, thousands of groups of hatchery and wild fish have been tagged on the Columbia, and the commercial and recreational fisheries, and escapements to hatcheries have been systematically sampled to obtain tag recoveries. CWT data have been routinely used by the Pacific Salmon Commission (PSC) working groups to estimate survival of Columbia River stocks.

The purpose of this study is to investigate the potential for using the CWT data base to examine the relationship between in-river factors (especially flow) and survival ~~in~~ of Columbia River chinook salmon.

Methods and Results

Estimating Survival from Coded-Wire-Tag data

Since the early 1970's approximately 2600 individual groups of chinook salmon have been marked with CWTs on the Columbia River. These tags have been applied primarily at hatcheries, although there has been some marking of wild stocks, and some of fish collected at dams. The motivation for tagging has been quite diverse, but most tags have been applied to compare experimental hatchery treatments, such as size and time of release, feeding regimes, or other hatchery practices. The data base on CWT data denotes three primarily types of tagging, experimental, production and index. Experimental tag groups are those mentioned previously, where agencies are experimenting with hatchery practices in some way. Production groups are fish reared

Please check these comments for accuracy and whether you understand what I mean! Note that comments are due by the 15th and I'm sure you'll be getting this on the 15th!

pg. 6, par. 4, last sentence -
Why is the "high correlation in flows between months" of noted importance? Isn't this generally true?

pg. 7, par. 1 -
In the equation for N_2, the p is lowercase, but in the text the P's are uppercase.

pg. 7, par. 4, sentence 5 -
"survival rates cannot have values less than zero" is only a problem when the distributions around the true survival rates would include negative values. In many applications, the survival rates are "far away enough" from zero (or one for that matter) so that this is not a problem.

Could the authors expand on the meaning of "... the potential for differential reliability of different survival rates. . ." and why that makes using survival rates as the y variable inappropriate.

pg. 11, Correcting for trends in ocean survival
This is a good idea, but can it be assumed or demonstrated that the Priest Rapids stock and the lower Columbia hatchery stocks are mixed in their ocean migration distribution, i.e, is the CWT sampling equal for the two groups in all sampling areas? If not, how would this affect (or bias) the results?

pg. 13, last par. -
scaled deviance (see Table 3) is not defined here, while delta scaled deviance is. Perhaps this definition should be included after the sentence "...than expected under the poisson." The next sentence after inserting the scaled deviance definition should say "The change in scaled deviance from one model to the next is the delta scaled devi.ante.". This would make this paragraph more correctly describe the columns in Table 3.

pg. 14, par. 2 -
The scale factor is the residual deviance of the most general model you used divided by its degrees of freedom.

Perhaps why the scale factor was so large is that you are missing some of the important factors in your model (eq. 9) . See also Table 9 and text on pg. 16, par. 4.

pg. 14, eq. 11 -
The subscript in the first likelihood in the equation should be i not j.

pg. 14, eq. 12 -
What is n?

pg. 14, last par. -
For the "layman reader" it might be helpful to have Table 5 show the "clearly significant" results of adding terms to the model.

pg. 15, par. 1 -
While this may be true, the authors just took the reader "deep into Bayesian Theory" which, for many readers, will lose them, i.e., this paragraph is much less understandable than the rest of the paper. The next paragraph does help. Perhaps this section could be rewritten in simpler language.

pg. 15, last par. -
Doesn't the chi-square significance test look at twice the change in negative log likelihood, (2 x 3.86)? See eq. 11.

Discussion -
It is appreciated that the authors note the substantial weaknesses of the study, particularly that: 1) the extent of impact of flow on survival is difficult to precisely quantify, especially when the "correct or best" model cannot be determined, and 2) the paper only identifies a correlative, not a causitive effect of flow on survival.

Review Hilborn et al. The relationship between river flow and survival. .

Recommendation:

1. Publish after revision.
2. Obtain professional editorial advice.

General Comments

This is potentially a very important paper in the field of hydroelectric salmon passage. The basic paper is sound, however it needs some work. I strongly recommend publication with revision.

The paper should stick to the original purpose of the project which was to develop measures of survival which can be compared to one another, and to other variables of interest. This paper cannot hope to be the "final solution" to the flow survival question. It should be a simple demonstration of 1) the use of CWT survivals, and 2) the use of downstream CWT data to control for non-hydroelectric effects. That is plenty. There is lots more that can be done, but leave it to others who are more familiar with the hydroelectric system. some ideas are given below.

The Introduction is a bit too ambitious and unnecessarily complex. It should focus on the circumstances that make this study important to salmon recovery in the Columbia Basin, while skipping the historical approach evident in the first two paragraphs. At the end of the introduction the reader should know that this paper is part of a long-term, economically and biologically critical debate over the role of river flow in salmon recovery. At stake are the very existence of salmon above Bonneville Dam, and hundreds of millions of dollars in electric bills. At intellectual issue are the extent to which salmon behavior depends on the historic river flow regimes, and the magnitudes of the risks imposed on these salmon populations by the flow regimes of the impounded Columbia River system. It 1s to the latter area, determining the magnitude of the risks imposed on fall chinook salmon in the mid-Columbia by impoundment, that your data analysis are relevant.

The tenor of the text may be considered too colloquial by some . A more formal style may be appropriate for a work of this gravity. For example, the term, "y variable," could be replaced by, "dependent variable." 'In a more formal paper, "out migration" could be replaced by "emigration".

The discussion section needs work. It may be a bit too apologetic, and it lacks a one-to-one correspondence to the methods and results.

Specific Comments, in order of occurrence in text . Please note that editorial comments are denoted, eO, and other substantive comments are denoted, O. Editorial comments follow other comments.

Review Hilborn et al. The relationship between *river flow and survival..*

o - p . 3, first para., next to last sentence, final clause, the wording is ambiguous and inaccurate. Please consider replacing this language with, "... and the summer chinook stocks may be of either life history type." It is erroneous to imply that-a summer chinook population could be a mixture of ocean-type and stream-type .

o - p . 3, second para., last sentence, a literature cite is needed here, and it needs to be made clear against what level of abundance the term, "increase" is applicable. If by "increase" it is meant, "return the runs to former or historical levels of abundance", then substitute this clause for the term increase.

o - p , 3, last para., third sentence. What is the relevance of conclusion (i) to the present paper? Was Raymond's work concerned with fish originating at Priest Rapids hatchery? Is this paper based on any data concerning the survival of non-hatchery fish? If not, it is *not* clear what sort of parallel is being drawn, or if a conclusion is being made.

o - p. 4, third paragraph, third sentence, consider being more specific than "physiological. condition"; how about "state of maturation?"

o - p. 4, fourth paragraph, this paragraph and the next three paragraphs are out of place, and the first sentence is not quite right. The Northwest Power Act was not passed to shed light on the relation between flow and the survivals and travel times of juvenile salmon. The fish and wildlife provisions of the Northwest Power Act were a new milestone in efforts to conserve and rebuild the basin's damaged and declining salmon runs. These efforts date at least to the earliest involvement of the Bureau of Commercial Fisheries during the 1920's, or perhaps earlier. Suggest the following actions, 1) change the first sentence to describe the NWPA as yet another attempt to turn the salmon runs away the path of destruction, 2) move this paragraph and the next three paragraphs (ending "... Columbia River stocks.") behind the second paragraph on page 3, and 3) make the last paragraph before the "Methods and Results" section on page 5 the first sentence of a *new* introductory paragraph to come before the current first paragraph on page 3. Why vait until the last paragraph to tell the reader what *you* came to do?

o - p . 4, last paragraph; the first three conditions, (i) - (iii) are not exhaustive or all inclusive. Which version of the Fish and Wildlife Program is being referred to in this statement? Were these three remedies singled out in the Fish and Wildlife Program as the three the Council could control, *or* would emphasize? What about "Increase in upstream survival of migrating adults?" or "Decrease in prespawning mortality for adults holding on or near the spawning grounds?", or "Decreases in fishing mortalities on subadults and adults?" Consider using the same construction as in the second sentence following, "Many management actions . . . including . . ."

o - p * 5, first line, the description of action (iii) is not

Review Hilborn et al. The relationship between river flow and survival.

accurate; increased flow and spill are two different actions. The action of spilling water does not require increased flow, nor are increased flows necessarily spilled. The spillway is one of three basic routes that may be available for a migrating juvenile to move through a dam. The other two routes take the fish into either the bypass system, or through the turbine. Not all dams have bypass, although all mainstem dams have spill and turbine routes.

o - page 6, third and fourth paragraphs. The mean monthly flow is net the *only* flow statistic that needs to be investigated, and the month in which the fish are released may not be the only time period to use.

In addition to sample mean monthly flow in the month of release, use the sample standard deviation (1) of daily flow during the month in which the fish were released, where n is the number of days in the month and the random variable, *X*, is the average daily flow. It may also be instructive to investigate other time measures of flow such as hourly flow, as the random variable, using both the mean and standard deviation as sample statistics. Please give an explanation of how- the flows are measured, or cite a reference.

An additional choice of random variable would be volume during some time period, as the integral of the time rate of change in volume, the flow. The relation between volume and survival may *or* may not be more instructive than the relation between flow and survival. The impact of a given flow level on survival may depend *on* pool elevation.

The choice of time interval over which to measure the independent variable may be important. The hypothesis that survival is proportional to flow points to mechanisms such as length of exposure to predation and other mortality factors inherent in the impoundments to explain the relation. Under this hypothesis the duration of migration should be proportional to flow, since velocity of migration (time rate of change in distance traveled) should be proportional to flow (time rate of change in volume). *Therefore, by picking a fixed time duration over which to measure the independent variable, information from outside the time horizon of the event may be Inappropriately applied to explain the event.* As a theoretical example, suppose that ninety percent of the migration is swept out of the hydroelectric system by high flows during the first week of May. Why then should the flows during the rest of May be a determinant of survival, if mortality factors associated with the hydroelectric system are responsible for the observed survivals?

As an alternative to mean monthly flow in the month of release, consider the average and variance of daily flow during a time period during which most (say ninety-five percent) of the migrants would have been passing McNary Dam. Such a time interval may be estimated as the 95% confidence interval about the mean of the time distribution of abundance of fall chinook in the sampling facility at McNary.

The problem of obtaining measures of flows as they occurred during the juvenile migration of each tag group, F(g) (Eqn. 2), is part of the general problem of synchrony to which studies of this nature are subject. It is important to employ measures of the physical environment that are synchronous with the migration of the population of juveniles to which the survival estimates apply.

o - page 6, fourth paragraph. The fact that there are "high" correlations between flows in adjacent months does not solve the problem of synchrony. There needs to be a section called, "Appropriate physical measures and results," where at least as much attention as has been paid to statistical model selection is paid to the selection and use of the independent variable, flow.

o - page 7, Appropriate statistics and results. The use of Bayesian approach Is good, but this paper may not be the place to make the general case for Bayesian inference. Decision theory and hypothesis testing are not equivalent tools. Cite references where Bayesian decision making approach has been explained, compared and contrasted with hypothesis testing and let it go at that. Focus on the relation between flow and survival.

o - page 12, first full para., sixth line from the top at right, "Some natural[ly] spawning . . . "; Juveniles from the naturally spawning fall chinook of the Hanford Reach of the Columbia River below the Priest Rapids that are closely related to the PR hatchery stock have been tagged with CWT every season since 1986. Technical reports are available from Matt Schwartzberg and CWT analyses are available from Mike Matylewich (Columbia River Inter-Tribal Fish Commission, 503-238-0667).

Since the Hanford fall chinook are the same kind of chinook as PR, it would be appropriate to acknowledge Hanford tagging as the longest continuous application of CWT to measure fisheries contributions and smelt to adult survival in a naturally spawning Pacific salmon population. Also, since the distributions of ocean fishery recoveries.for PR and Hanford Reach are similar, this would validate the extension of the results of the flow survival model to naturally spawning fall chinook in the mid-Columbia. The use of Priest Rapids CWT tag recoveries as proxies for calculating the vital statistics of at least some of the naturally spawning fall chinook populations of the mid-Columbia has been validated by data, as is not usually the case in CWT studies.

The validity of hatchery CWT returns as proxies for their naturally spawning counterparts figures very prominently in supporting the assertions and conclusions reached in the first paragraph on page 18.

o - page 13, General issues . . . . first para. last sentence.

Review Hilborn et al. The relationship between river flow and survival..

Please clarify whether Bonneville and Washougal had almost no releases of CWT marks, or *just no* on-station releases during this time period.

o - page 18, first paragraph. See comments for page 12, above. The validity of this assertion rests on the similarity, or lack thereof, of hatchery fish to naturally spawning fish. Given the fact that a number of authors, including Hilborn, Waples and others, consider hatchery fish inferior in many respects, including survival, to their naturally spawning counterparts, the fact of similarity between PR hatchery and the naturally spawning fall chinook has to be established. The validity of extending these results to other types of salmon spawning in other parts of the Columbia Basin bumps up against the problem of synchrony, discussed above.

o - page 18, second paragraph. See comments for page **12 above.** Approach the applicability of results in terms of solving the problem of synchrony.

o - page 19, first paragraph; the findings are consistent with the hypothesis that survival of juvenile emigrants is positively related to flow. The hypothesis is also consistent with known mechanisms of mortality during emigration.

o - page 19, second paragraph, third sentence; please explain how flow "undoubtedly" could impact conditions influencing survival in the estuary; cite a reference. Why would any of the differences identified in this paragraph impact lower river and upriver stocks differently? Poor survival of upriver stocks relative to lower river stocks may be due to factors that are covariates of flow, such that flow has *no* direct impact on survival. If hydroelectric stress is reduced during higher flows, *or* if predation in the hydroelectric system is reduced during higher flows, or diseases associated with elevated temperatures are impeded during higher flows, or if migratory delay induced residualism is decreased during higher flows, then all of these mortalities would not be experienced by the lover river stocks. On the other hand, upriver stocks would suffer in the estuary right along with *lower river* stocks, and so forth. Frankly, I find these apologies for comparing upriver to *lower* river stocks unnecessary.

o - The Discussion section needs to be expanded to correspond more closely to **the** results.

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eO - p. 3, first para., next to last sentence, missing word, "life" between "ocean-type" and "life" following "fall chinook."

eO - p. 3, first para., last sentence, extra word, "out" before "migrate."

eO - p. 3, last para., second sentence, extra word, "out" before "migrant"; "migrant" is the wrong word, it should be "migrating."

Review Hilborn et al. The relationship between river flow and survival. .

Use of "out" is redundant, since smelts only migrate in one direction, out, although smolts do not necessarily migrate, since they may residualize.

eO - p. 3, last' para., third sentence, and elsewhere in the manuscript please consider replacing the term, "out migration," with, "migration," or with "migration to the sea", *or* "downriver migration," There are also the alternatives, "emigration" and "emigrant." Consider replacing all occurrences of "out migrant" with "emigrant."

60 - p. 4, third paragraph, first sentence, awkward "construct Ion, colloquial language.

eO - p. 4, last paragraph; Management action (ii); a verb is needed here and there, " . . . juvenile salmon are collected . .."

eO - page 6, first and second lines; awkward construction; delete all but, "where tagging is done to determine the contribution of hatchery to fisheries and spawning escapements."

eO - page 6, second paragraph, next to last line and third paragraph, second line; The use of "we" represents a change of person. Decide on which person the paper is going to be written in, and stick to it. I advise against the use of pronouns in the first and second person, although *some* journals find this acceptable.

eO - Page 9, Appropriate statistical model, line before Eqn. 5, extra words, "*given* the" before "predicted" and missing word, "model" after "probability,"

eO - page 13, first line after eqn 10, "DM" needs to match the form used in eqn. 10, arid the wrong word, "defiance," is used in place of "deviance."

eO - p. 22, Check spelling on References; e.g. Lebreton et al. reference, "unified," see also Pascual 1993.

eO - End of editorial comments. Please *note* that time did not permit complete editing. The paper needs careful editorial attention.

-Respectfully submitted, Phil Mundy, 503-636-6335

Notes

1. Snedecor and Cochran (1980), Statistical Methods, Seventh Edition, p. 31, sect. 3.5, Iowa State Univ. Press.

November 15, 1993

Implementation Planning Process
Scientific Review Group
December 10, 1993

Synthesis of Peer Review

Subject: ***The relationship*** *between* ***river flow*** *and* ***survival*** *for* ***Columbia River*** *Chinook* ***salmon***, Hilborn *et al.*

GENERAL PINDINGS

The paper has the potential to make a significant contribution in the field of hydroelectric salmon passage. However, as it stands, the paper is not suitable for circulation or publication. The SRG recommends substantial revision.

The subject matter is especially significant and timely in that it deals with subyearling fall chinook, an important group that has received scant attention in the past. It is innovative in that it attempts to estimate the effects of water flow on juvenile migrant salmon survival using coded wire tag (CWT) data, after adjusting for a control assumed to be a proxy variable for ocean conditions.

Perhaps the most significant criticism of the manuscript involves the lack of information on the extent to which the downstream populations are biologically comparable to the upriver populations. Further explanation of the rationale for the selection of control populations from downstream hatcheries needs to be made in order to validate this approach.

Another significant *criticism* involves a lack of focus on clearly defined objectives. The paper should hew closely to the original purpose of the research project which was to develop measures of survival which could be statistically compared to one another, and to other variables of interest. As a pioneering effort in measurement and analysis, this paper cannot hope to be the "final solution" to the flow-survival question. The focus of the paper should be a simple demonstration of 1) the potential of using CWT data to estimate survivals "for evaluation of environmental impacts on salmon, and 2) the use of downstream CWT data to control for non-hydroelectric effects. While the paper might be expanded to cover hydroelectric passage problems more thoroughly, the authors would need the help of others who are more familiar with the hydroelectric system in order to do this.

A number of the reviewers found the general tenor of the text to be colloquial A more formal style would be more appropriate for a work of this gravity. For example, the term, "y variable, " should be replaced by, "dependent variable. " In a more formal paper, "out migration" should be replaced by "emigration".

The Introduction is too ambitious and unnecessarily complex. It should focus on the circumstances that make this study important to salmon recovery in the Columbia Basin, while bypassing the historical approach evident in the first two paragraphs. At the end of the Introduction the reader should know that the paper is part of a long-term, economically and biologically critical, debate over the role of river flow in salmon recovery, and that the focus is on fall chinook. At stake are the very existence of salmon above Bonneville Dam, as well as hundreds of millions of dollars in electric bills each year. At intellectual issue "are the extent to which salmon behavior depends on the historic river flow regimes, and the magnitudes of the risks imposed on these salmon populations by the flow regimes of the impounded Columbia River system. It is to the latter area, determining the magnitude of the risks imposed on fall chinook salmon in the mid-Columbia by impoundment, that the data analysis is relevant.

Finally, the discussion section needs work. It is too apologetic, and it lacks a one-to-one correspondence to the methods and results.

OUTLINE OF KEY CONCERNS

1. Specify the geographic range to which the results may apply.

2. Provide a more rigorous biological description of the populations of salmon included in the study to which the conclusions may apply.

3. Address key historical and other references, including alternative explanations for the data.

4. Carefully examine and document the reason for selecting the downriver control populations that are used to correct for trends in survival in areas outside the geographic range of the hydroelectric system.

5. Carefully evaluate the selection of the independent variable representing flow with respect to its physical and temporal properties.

6. Focus the paper on evaluating the potential relation between flow and survival, lending less effort to discussion of Bayesian statistical methods and general history of the Columbia Basin.

7. Correct misstatements

DOCUMENTATION OF KEY CONCERNS

1. Specify the geographic range to which the results may apply.

It is essential in identifying the problem, to separate the upper Columbia from the mid-Columbia for two reasons, the fist being that no salmon exist in the upper Columbia (above Chief Joseph Darn), and the second being that the projects in the mid-Columbia (below Grand Coulee Darn) are run-of-the river projects with limited storage capacity. Since the authors relate survival to flow at McNary, it is important to make this distinction in the conclusions and discussion. To increase precision with respect to location, consider changing, "The slope of the flow-survival relationship is lower, suggesting that a 100 kcfs increase in flow would result in a 26% increase in suMval, ...” [page 17] to the more accurately stated, “ . . increase in flow at McNary would result . . . .”

2. **Provide a *more* rigorous biological description of the populations of salmon included in the study, and to which the conclusions may apply.**

Throughout the document, the authors do not clearly state whether the paper refers to subyearling or yearling migrants or Snake v. the mid-Columbia. For example, it is a long *time* before they say that Priest Rapids is a fall chinook with subyearling migrants, yet the focus on ocean-type chinook is one of the most unique and useful aspects of the paper. practically all other work has concentrated on spring chinook yearling migrants. This is an extremely important distinction that should be clarified in the Introduction and the Title.

The authors need to distinguish between Snake River studies and mid-Columbia studies. For example, please clarify the relevance of conclusion (i) [p. 3, last para., third sentence] to the present paper. The fact that Raymond’s work had to do with Snake River yearling chinook rather than mid-Columbia subheading chinook should be clarified.

The authors are also remiss in not contrasting the highly significant biological differences between tule and upriver bright fail chinook stocks.

The authors need to address the issue of whether the results apply to non-hatchery fish. Is this paper based on any data concerning the survival of non-hatchery fish? If not, it is not clear what sort of parallel is being drawn, or if a conclusion is being made. Juveniles from the naturally spawning fall chinook of the Hanford Reach of the Columbia River below the Priest Rapids that are closely related to the PR hatchery stock have been tagged with CWT every season since 1986. Since the distributions of ocean fishery recoveries for Priest Rapids hatchery fish and Hanford Reach wild fish are similar, this would help to validate the extension of the results of the flow survival model to naturally spawning fall chinook in the mid-Columbia. The use of Priest Rapids CWT tag recoveries as proxies for the vital statistics of at least some of the naturally spawning fall chinook populations of the mid-Columbia has been validated by the results of the wild fish tagging studies. This is not usually the case in CWT studies.

3. **Address key historical and other references, including alternative explanations for the data.**

For example, Sims and Ossiander (National Marine Fisheries Service, Coastal Zone and Estuarine Studies Division, Seattle); Pacific Salmon Commission Hanford Reach tagging program (columbia river Inter-Tribal Fish Commission, Portland); Bill Norman’s M.S. Thesis; Pacific Salmon Commission technical report 90-3; Pete Lawson’s recent paper in Fisheries, 18(8). There are models that contend that flow is a controlling variable with respect to juvenile survival only up to flows of about 230 kcfs. These models are known as the “broken stick model” and the “threshold” model, as further explained below.

Bill Norman, in his M.S. thesis [Factors Controlling Variation of Naturally Spawning

Fall Chinook Salmon in the Upper Columbia River. M.S. Thesis, U.W. 1992] examined the relationship between flow and survival for naturally spawned chinook from Vernita Bar, just below Priest Rapids Dam. He found higher survival at low flows - the opposite of this study. It should be clear to the audience that the authors are, indeed, aware of the Norman work.

An alternative explanation of the sample size is possible. The CWT Priest Rapids data set does not appear to all reviewers to be as large as represented. Some of-the 23 data sets over the eleven year period may be replicates, or pseudo-replicates, in that 12 groups designated as individual "releases" by the authors are composed of four sets of three releases made within the same date. These 12 tag lots might be considered four releases by some reviewers, for a total of 15 individual releases. The reduction in releases led to an imbalance in the number of releases by month, leaving ten during June and only five during May. Hence the emphasis on flow conditions in May could be misplaced.

The data may not be best explained by a single linear model. Some researchers believe there are two stages, or parts, to the relation between flow and survival. When described by the fit of two linear models, this is called the "broken stick" model. The present data set may be consistent with such a two part model. The domain of the frost part would be 100-230 cfs, and the domain of the second would be 230-400 cfs. In the first phase, survival is an increasing linear function of flow, and in the second the slope of the line may not be different from zero. From the point of view of proponents of the broken stick model, the use of the single linear representation may obscure the question of why 230 cfs seems to be a turning point in the relation between flow and juvenile migrant survival. The authors should also examine the suitability of non-linear models that have been used for the yearling chinook flow/survival relationship.

An additional concern is that the four survival points corresponding to flows below 200 cfs all occur during June, whereas the higher survival points corresponding to higher flows are a mixture of May and June releases. Given the seasonal trend toward increasing temperatures with later dates, temperature may be the mortality mechanism associated with lower flows.

4. Carefully examine and document the reason for selecting the downriver control populations that are used to correct for trends in ex-hydroelectric survival.

An important technical concern is the author's use of the lower river hatcheries as ocean controls for Priest Rapids Hatchery. To be controls, all of the groups should experience the same conditions except for juvenile passage between Priest Rapids and Bonneville. The authors state that their analysis of the tag groups indicates that Bonneville, Grays River, Washougal and Cowlitz hatcheries had ocean distributions similar to Priest Rapids Hatchery and could serve as controls. But are the data actually consistent with this conclusion? The groups proposed as controls are all representative of a group of fall chinook known as tules, a distinctive race of lower Columbia River fall chinook. Tules have a generally southerly distribution concentrated off Vancouver Island and Washington. The Priest Rapids fail chinook, on the other hand, are known as upriver brights. Brights have an ocean distribution that is markedly different than that of the tules. Brights are more northerly in their distribution, being caught mainly off northern BC and Alaska.

For example, the Pacific Salmon Commission technical report 90-3, shows the differences in the distribution in fishing mortality between Priest Rapids and the Bonneville and Cowlitz fall chinook (Grays River is not a PSC indicator stock and is not included). The key concept that needs to be addressed by the authors is the split in distribution between northern BC (N-BC) and the west coast Vancouver Island (WCVI). The latter represents the bulk of mortality for the Bonneville tules, for example, but is relatively minor for the brights. On the other hand, the PSC report indicates that Alaska is the biggest source of fishing mortality for the brights, but accounts for none of the mortality on Bonneville tules.

In addition to factors associated with oceanic distribution, poor survival of upriver stocks relative to lower river stocks may be due to factors that are covariates of flow, such that flow has no direct impact on survival. If hydroelectric stress is reduce-d during higher flows, or if predation in the hydroelectric system is reduced during higher flows, or diseases associated with elevated temperatures are impeded during higher flows, or if migratory delay induced residualism is decreased during higher flows, then all of these mortalities would not be experienced by the lower river stocks. On the other hand, upriver stocks would suffer in the estuary right along with lower river stocks, and so forth.

5. Carefully evaluate the selection of the independent variable representing flow with respect to its physical and temporal properties.

The problem of obtaining measures of flows as they occurred during the juvenile migration of each tag group, F(g) (Eqn. 2), is part of the general *problem of synchrony* to which studies of this nature are subject. It is important to employ measures of the physical environment that are synchronous with the migration of the population of juveniles to which the survival estimates apply. The fact that there are 'high" correlations between flows in adjacent months. does not solve the problem of synchrony. There needs to be a section called, "Appropriate physical measures and results," where at least as much attention as has been paid to statistical model selection is paid to the selection and use of the independent . variable, flow.

The choice of time interval over which to measure the independent variable may be important. The hypothesis that survival is proportional to flow points to mechanisms such as length of exposure to predation and other mortality factors inherent in the impoundments to explain the relation. Under this hypothesis the duration of migration should be proportional to flow, since velocity of migration (time rate of change in distance traveled) should be proportional to flow (time rate of change in volume). *Therefore, by picking a* ***fixed*** *time* ***duration*** *over which to measure the independent variable, information* ***from outside the*** *time* ***horizon*** *of the event may be* ***inappropriately*** *applied to* ***explain the*** *event.*

6. **Focus the paper on flow survival, lending less effort to discussion of statistical methods and general history of the Columbia Basin.**

It still is not clear how a simple linear regression analysis would have led to conclusions different from those offered by Bayesian methods. The discussion of decision theory [page 8, 9 and 10] may not be convincing. The question, " . . .if we fail to reject the null hypothesis do we act as if there is no relationship between flow and survival?" [page 8, paragraph 3] has a straightforward answer. The answer is, "Yes, if we have appropriately set the alpha level to correspond to our Willingness to accept type 1 and type 2 errors. " The second question, "If we do reject the null hypothesis, how much flow do we allow?" [page 8, paragraph 3] has the same answer as the one provided later, "An increment of flow gives an increment of survival." The manager has to decide how far up the scale it is prudent to go, depending on the goals, which in turn depend on many factors, some probably subjective. The confidence interval shows the manager that the further away from the mean the response gets, the less confidence can be placed in projecting performance on the next increment.

The choice of an alpha level is not necessarily, ". .a totally arbitrary decision. " It may be true for some investigators, but it should not be. Any manager should make a reasoned judgement as to an appropriate alpha level depending on the circumstances, such as the cost of being wrong.

7. Correct misstatements

The Northwest Power Act was not passed to shed light on the relation between flow and the survivals and travel times of juvenile salmon [p. 4, fourth paragraph, first sentence]. The fish and wildlife provisions of the Northwest Power Act were a new milestone in efforts to conserve and rebuild the basin's damaged and declining salmon runs. These efforts date at least to the earliest involvement of the Bureau of Commercial Fisheries during the 1920's, or perhaps earlier.

The first three conditions, (i) - (ii) are not exhaustive or all inclusive [p. 4, last paragraph], and it is not clear to which version of the Fish and Wildlife Program is being referred to in this statement. Were these three remedies singled out in the Fish and Wildlife Program as the three the Council could control, or would emphasize? What about "Increase in upstream survival of migrating adults?" or "Decrease in prespawning mortality for adults holding on or near the spawning grounds?", or "Decreases in fishing mortalities on subadults and adults?" Consider using the same construction as in the second sentence following, "Many management actions . . .including . .."

The description of action (iii) [p. 5, first line] is not accurate; <u>increased flow</u> and <u>spill</u> are two different actions. This point should probably be broken into two actions at the semicolon. The action of spilling water does not require increased flow, nor are increased flows necessarily spilled. The spillway is one of three basic routes that may be available for a migrating juvenile to move through a dam. The other two routes take the fish into either the bypass system, or through the turbine. Not all dams have bypass, although all mainstem dams have spill and turbine routes.

While no survival studies have been done that have evaluated flow [page 5, first paragraph, last sentence], many travel time studies have been done. The reviewers know of no studies that have shown slowing of emigrating juvenile salmon in the mid-Columbia Reach.

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Appendix B2: Responses to Peer Reviews of Hilborn et al. (1993b)

General comments on the initial manuscript “The relationship between river flow and survival for Columbia River chinook salmon,” authored by R. Hilborn, R. Donnelly, M. Pascual, and C. Coronado-Hemandez (1993 b), can be summarized into the three points below.

1) Comment - Refine purpose of the paper to investigate and develop measures of survival which could be statistically compared to each other. (Mundy, SRG)

Response - The original draft was split into two phases. Phase I was completed and published by the Bonneville Power Administration in November 1993. This report (Phase II) concentrated on the actual analysis of the CWT data, attempting three different approaches, with and without adjustment for the probability of transportation of a portion of the releases from Priest Rapids.

2) Comment - Expand paper to a multivariate analysis, including factors other than flow in determining the adult return component, such as temperature, turbidity and transportation. (Giorgi, Mundy, Stevenson) Carefully evaluate the selection of the independent variable representing flow with respect to its physical and temporal properties. (Giorgi, Mundy, Stevenson, SRG)

Response - This revised report included environmental covariates of temperature, turbidity, spill, percent of spill of total flow, as well as flow. In addition, the total weight of chinook, coho and steelhead salmon releases per season were included as a preliminary investigation into the effect of total biomass on the adult survival rate. The problem ofs ynchrony is a difficult one to which a general solution has not been found. A more representative variable was attempted by representing the environmental covariates by a linear regression characterizing the month following a release from Priest Rapids. The intercept represents the initial condition experienced by all of the released group and the slope is the average change from that initial condition. This initial condition is a better variable to be regressed upon, as all of the fish experience this condition, eliminating the argument that this particular variable is measuring an event outside of the qualified time horizon. Further analysis of the slope of the variable in future studies may elicit information as to the validity of taking a linear regression of a month's length.

3) Comment - Carefully examine and document the reason for selecting the downriver control populations that are used to correct for trends in survival in areas outside the geographic range of the hydroelectric system. (Giorgi, Mundy, SRG, Stevenson, Williams)

Response - A cluster analysis indicated which of the major fall chinook hatchery stocks were most similar to the Priest Rapids Hatchery stock by ocean catch distribution. Within the five closest potential reference stocks, release groups were selected for similarity to the Priest Rapid's releases on the basis of time of release, development stage at the time of release and how the release group had been treated while at the hatchery (e.g. production, experimental, etc.). Subsequent statistical analysis of these subgroups for homogeneity to the Priest Rapids hatchery stock failed to show that any reference stock had a similar ocean catch distribution history. Five separate analyses were completed employing each of the stock as a references. The results for each choice were compared to ascertain the influence of reference selection. The dissimilar outcomes for the analyses confirmed reference selection greatly affected results.

Appendix C: Data Tables Used in Analysis

Table of Tables

Table Cl: Priest Rapids hatchery releases of fall chinook salmon for 1987, expanded recaptures grouped by state and year 1988-1992. A test of homogeneity between the nine releases is rejected: ($P(\chi^2_{120} > 266.62) \approx$ O)

Recovery Year	51915	51916	51917	51918	51919	51920	51921	51922	634128
					Alaska				
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.07
1990	29.20	28.11	24.47	27.74	11.60	7.88	11.60	6.09	47.66
1991	18.03	11.27	8.27	6.44	0.00	3.22	4.19	3.22	13.41
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					British Columbia				
1988	0.00	0.00	1.39	1.39	6.96	1.39	0.00	0.00	0.00
1989	18.43	6.98	9,05	15.43	3.00	0.00	0.00	0.00	9.81
1990	5.72	26.64	6.07	34.94	7.20	13.47	20.44	16.24	59.17
1991	6.56	26.54	32.48	11.55	4.45	16.22	3.27	9.02	17.86
1992	0.00	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00
					Washington				
1988	0.00	0.00	0.00	8.28	0.00	0.00	0.00	0.00	3.19
1989	0.00	0.00	2.25	3.90	0.00	27.66	0.00	2.45	3.42
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.14
1991	2.30	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					Oregon				
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50
1990	0.00	0.00	0.00	2.43	0.00	0.00	0.00	9.00	0.00
1991	0.00	0.00	0.00	3.67	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C2: Release data used in river conditions/adult survival rate analysis

release year	release &y	Priest Rapids vpa	Grays River vpa	Bonneville Brights vpa	Cowlitz Vpa	Washougal vpa	Tanner's Creek vpa
76	182	0.0565	NA	NA	NA	NA	NA
76	182	-0.0624	NA	NA	NA	NA	NA
77	177	0.0176	0.0009	NA	NA	0.0363	0.0033
78	177	0.0102	0.0007	NA	0.0371	0.0098	NA
79	142	0.0210	0.0025	0.0609	NA	NA	0.0065
79	178	0.0051	0.0025	0.0609	NA	NA	0.0065
79	178	0.0052	0.0025	0.0609	NA	NA	0.0065
79	178	0.0036	0.0025	0.0609	NA	NA	0.0065
80	177	0.0115	0.0037	0.0278	0.0032	0.0077	O.(UM.5
81	174	0.0089	0.0068	0.0281	0.0195	0.0062	0.0060
81	137	0.0265	0.0068	0.0281	0.0195	0.0062	0.0060
82	166	0.0169	0.0017	0.0250	0.0034	0.0037	0.0035
82	137	0.0327	0.0017	0.0250	0.0034	0.0037	0.0035
83	143	0.0271	0.0035	0.0270	0.0084	0.0148	0.(2099
83	172	0.0450	0.0035	0.0270	0.0084	0.0148	0.0099
84	164	0.0427	NA	0.0370	0.0234	0.0423	0.0013
84	164	0.0503	NA	0.0370	0.0234	0.0423	0.0013
84	164	0.0520	NA	0.0370	0.0234	0.0423	0.0013
85	161	0.0610	0.0583	O.(M54	0.0270	0.0443	0.0878
85	161	0.0619	0.0583	0.0454	0.0270	0.0443	0.0878
86	90	0.0327	0.0072	NA	0.0064	0.0105	NA
86	162	0.0077	0.0072	NA	0.0064	0.0105	NA
87	12.$	0.0089	NA	0.1639	0.0041	0.0029	0.01s9
87	124	0.0136	NA	0.1639	0.0041	0.0029	0.0189
87	124	0.0117	NA	0.1639	0.0C41	0.0029	0.0189
87	124	0.0158	NA	0.1639	0.0041	0.0029	0.0189
87	123	0.0024	NA	0.1639	0.0041	0.0029	0.0189
87	123	0.0037	NA	0.1639	0.0041	0.0029	0.0189
87	123	0.0037	NA	0.1639	0.0041	0.0029	0.0189
87	146	0.0053	NA	0.1639	0.0041	0.0029	0.0189
87	175	0.0081	NA	0.1639	0.0041	0.0029	0.0189
88	169	0.0018	NA	0.0021	0.0008	0.0046	O.(NI 16
89	179	0.0029	0.0015	0.0094	0.0013	NA	0.0056

Table C3: River conditions used in analysis.

release year	release day	flow.a	flow.b	spill.a	spill.b	turb.a	turb.b	tempt.a	tempt.b	spill ratio	spill ratio var	spill ratio cv
76	182	241744.83	-167.0772	88245.0739	-1985.8785	1.9643	0.0270	15.4424	0.1113	0.2565	0.0202	0.5542
76	182	241744.83	-167.0772	88245.0739	-1985.8785	1.9643	0.0270	15.4424	0.1113	0.2565	0.0202	0.5542
77	177	94852.96	-101.0126	O.teal	0.0000	4.6874	0.0200	19.5760	-0.0274	0.0003	0.0000	NA
78	177	217771.43	-1380.1587	-4.9261	10.9469	2.7628	-0.0293	16.4329	0.0879	0.0007	0.0000	3.6682
79	142	265992.86	-4134.1270	45321.6749	-2214.03%	1.8461	0.0143	13.2581	0.0923	0.0734	0.0062	1.0715
79	178	143738.18	-12729338	0.0000	0.0000	2.9404	0.0221	16.9910	0.1435	0.0000	0.0000	NA
79	178	143738.18	-1229338	0.000o	0.0000	2.9404	0.0221	16.9910	0.1435	0.0000	0.0000	NA
79	178	143738.18	-1272.9338	0.0000	0.00130	2.9404	0.0221	16.9910	0.1435	0.0000	0.0000	NA
80	177	223920.44	-3308.9217	3910.5911	-1%.55 17	2.4333	0.0134	16.1029	0.1285	0.0070	0.0004	2.8967
81	174	310043.60	-3949.261 1	81483.9901	-3720.7718	2.2466	0.0156	15.1725	0.0578	0.121-	0.0197	1.1523
81	137	199947.29	9125.8621	-21158.1281	11938.6973	2.8419	-0.0224	12.2565	0.0695	0.4333	0.0711	0.6153
82	166	430767.49	-4091.2425	257445.0739	-3029.5293	2.0145	-0.0 172	14.5375	0.0842	0.5766	0.0176	0.2299
82	137	382629.06	-2 941.5709	193980.7882	-2769.2118	2.1010	0.0034	11.673'7	0.0686	0.4567	0.0027	0.1130
83	143	390880.05	-4354.8714	211188.9163	-5592.8298	?.2264	-0.0205	14.2354	0.0772	0.4086	0.0138	0.2872
83	172	210916.01	-168.9108	-1874.1379	278.2430	1.8131	0.0337	16.0351	0.0849	0.0090	0.0010	3.5904
84	164	389842.61	4747.8654	20$853.9409	-$500.8210	1.5493	0.0262	13.5139	0.1305	0.4423	0.0092	0.2166
84	164	389842.61	-47.$7.8654	204853.9409	-$500.8210	1.5493	0.0262	13.5139	0.1305	0.4423	0.0092	0.2166
84	164	389842.61	-4747.8654	204853.9409	-4500.8210	1.5493	0.0262	13.5139	0.1305	0.4423	0.0092	0.2166
85	161	200024.53	-3191.9759	0.0000	0.0000	2.3894	0.0362	15.2535	0.1694	0.0000	0.000o	NA
85	161	200024.53	-3191,9?59	0.0000	00000	2.3894	0.0362	15.2535	0.1694	0.0000	0.0000	NA
86	90	2578 S8.97	-251.5107	425100000	437.2222	1.6867	0.0280	7.6836	0.0731	0.1438	0.0073	0.5922
86	162	25865443	-6055.4871	2.!858.3251	-1256.1193	1.9956	0.0059	15.4875	0.1300	0.0447	0.0038	1.3797
87	124	258144.29	-3610.158:	70013.2266	-2750.3448	3.1227	-0.0099	11.2150	0.1040	0.1499	0.0144	0.8019
87	124	268144.29	-3610.1587	70013.2266	-2750.3448	3.1227	-O.(KW9	11.2150	0.1040	0.1499	0.0144	0.8019
87	124	268144.29	-3610.158:	70013.2266	-2750.3448	3.1227	-0.0099	11.2150	0.1040	0.1499	0.0144	0.8019
87	124	268144.29	-3610.1587	70313.2266	-2750.3448	3.1227	-O.(XW9	11.2150	0.1040	0.1499	0.0144	0.8019
87	123	261659.75	-3068.0241	63423.7685	-2258.0569	3.0756	-C).(X)53	11.06 -	0.1095	0.1496	0.0144	0.8014
87	123	261659.75	-3068.024 1	63423.7685	-2258.0569	3.0756	-0.0053	11.061:	0.1095	·0.1496	0.0144	0.8014
87	123	261659.75	-3068.0241	63423 .?685	-2258.0569	3.0756	-0.0053	11.0617	0.1095	0.1496	0.0144	0.8014
87	146	206426.38	-3572.9858	987.4877	-52.7504	2.7542	0.0153	12.9293	0.1695	0.0017	0.000 I	4.3385
87	175	110719.26	-327.2469	0.0000	0.0000	3.4062	0.0054	18.7630	0.0505	0.0000	0.0000	NA
88	169	145405.74	-1611.9595	0.0000	0.0000	3.5%1	-0.0031	17.6892	0.0786	0.0000	0.0000	NA
89	179	123858.23	-995.0274	0.0000	0.0000	3.4569	0.0069	18.2578	o.c041	O.0000	0.0000	NA

Table C4: NMFS Data from McNary Dam transportation studies 1986-1988, used in calculation of fall salmon transportation-control ratio.

		control					treatment				
year	release batch	# released	# dams recovered	fisheries # recovered	hatcheries # recovered	spawning grounds # recovered	# released	# dams recovered	fisheries # recovered	hatcheries # recovered	spawning grounds # recovered
86	1	1000O	0	10	4	0	10000	3	11	2	0
86	2	10000	[illegible]	9	7	0	10000	0	3	1	0
86	3	loom	[illegible]	13	5	0	loom	0	9	5	0
86	4	10000	3	12	13	0	10WO	6	26	15	0
86	5	10000	2	13	5	0	10000	2	34	14	1
86	6	10000	3	10	7	0	10000	6	30	6	3
86	7	1000O	3	8	1	1	100CKI	12	43	4	I
86	8	1000O	0	·	0	1	1000O	8	32	4	1
86	9	100CNI	1	8	0	0	10000	11	33	0	0
8 6	10	10W3	0	5	0	0	100W	5	43	2	4
86	11	10000	1	8	0	1	10000	9	46	9	0
86	12	5836	3	0	0	0	4557	2	15	0	0
87	1	1000O	2	4	4	0	10003	7	42	7	3
87	2	9146	3		4	0	9146	6	11	1	2
87	3	9753	1	5	1	0	9834	8	24	2	o
87	4	100W	5	17	0	0	10001	5	21	5	0
87	5	1000O	7	9	[illegible]	1	1000O	11	22	1	2
87	6	9392	4	10	2	1	9392	21	51	1	6
87	7	10000	8		5	2	10000	29	93	10	5
88	1	10002	[illegible]	4	0	0	loom	3	2	1	0
88	2	10002	0	0	0	0	10CQ3	0	2	1	0
88	3	1000Z	2	1	2	0	10002	4	1	1	0
88	4	10W2	0	1	0	0	10002	0	6	2	0
88	5	10002	0	2	0	0	10002	2	15	0	0
88	6	10000	0	3	0	1	loom	2	18	0	1

Correlations of Total Adult Catch to VPA estimates

Table C5: Correlation of percentage of total adult returns to vpa estimates of percent survival to age 2 for each hatchery in this analysis.

Hatchery	Total adult catch %	Spawning ground catch %	Hatchery catch %
Bonneville Brights	0.937	0.042	0.581
Cowlitz	0.984	0.658	0.937
Grays River	0.978	0.795	0.977
Priest Rapids	0.941	0.-$39	0.935
Tanner Creek	0.954	0.279	0.803
Washougal	0.990	0.754	0.955

Table C6: Freeze-branded chinook released at Priest Rapids and sampled at McNary Dam.

Brand	Brood	Release date	N
RA-T-1	84	6/1 2/85	1397
LA-T-1	85	6/10/86	2028
LA-T-4	85	6/10/86	1241
RA-T-2	86	6/'08/87	1363
RA-T-3	86	6/22/87	1409
RA-R-2	87	6/18/88	425
LA-R- 1	87	6/06/88	579
LA-R-2	87	6/09/88	494
LA-R-4	87	6/1 2/88	.$29
LA-T- 1	88	6/1 2/89	666
LA-T-2	88	6/29/89	178
LA-T-3	88	6/'22/89	335
LD-T- 1	88	6/1 8/89	450
LD-T-3	88	6/27/89	213
RA-H- 1	89	6/07/90	372
RA-H-2	89	6/10/90	333
RA-UP- 1	89	6/1 9/90	364
RA-UP-3	89	6/16/90	384
RD-H-1	89	6/13/%)	214
LA-u- 1	90	6/26/91	578

Brand	Brood	Release date	N
LA-U-2	90	6/23/91	504
LA-U-3	90	6/20/91	605
LD-U- 1	90	6/14/91	552
LD-U-3	90	6/1 7/91	490
RA-U- 1	91	6/24/92	537
RA-U-3	91	6/15/92	467
RA-U-2	91	6/1 2/92	470
RD-U-1	91	6/'2 1/92	487
RD-U-3	91	6/1 8/92	465
LA-U-1	92	6/1 8/93	658
LA-U-2	92	6/15/93	286
LA-U-3	92	6/24/93	402
LD-U-1	92	6/2 1 /93	329
I-D-L--3	92	6/27/93	331
LA-H- 1	93	6/20/94	243
LA-H-2	93	611 4/94	420
LD-H-1	93	6/1 6/94	220
LD-H-2	93	6/1 2/94	479
RA-H- 1	93	6/1 8/94	207

Table C7: Data matrix used for Hilborn et al. model (5 & 6) regressions.

relyr	marked	obs.return	flow	spill	turb	tempt	spill.ratio	tonnage	hatchery
7 6	132004	2179.15	239489.29	61435.71	2.33	16.94	0.26	2629033004	priest
76	152412	3049.78	?39489.?9	61435.71	2.33	16.94	0.26	2629033004	priest
7'7	147338	1238.24	93489.29	0.00	4.%	19.21	0.00	2676503847	priest
78	152S32	782.70	199139.29	142.86	2.37	17.62	0.00	2696194438	priest
79	48130	409.85	210182.14	15432.14	2.04	14.50	0.07	3938009027	priest
79	17467	29.59	126553.57	0.00	3.24	18.93	0.00	3938009027	priest
79	5316	6.33	126553.57	0.00	3.24	18.93	0.00	3938009027	priest
79	82243	71.32	126553.57	0.00	3.24	18.93	0.00	3938009027	priest
8 0	147145	$435.09	179250.00	1257.14	2.61	17.84	0.01	4122663'209	priest
81	194649	978.07	256728.57	31253.57	2.46	15.95	0.12	3791298958	priest
81	42089	466.98	323146.43	140014.29	2.54	13.19	0.43	3791298958	priest
82	262176	1468.12	375535.71	216546.43	1.78	15.67	0.58	382668?145	priest
82	48700	453.55	342917.86	1565%.43	2.15	12.KI	0.46	3826687145	priest
83	204141	1687.85	332089.29	135685.71	1.95	15.28	0.41	3798444366	priest
83	202388	48130.77	208635.71	1882.14	2.27	17.18	0.01	3798444366	priest
84	74170	1668.87	325746.43	144092.86	1.90	15.28	0.44	4113488611	priest
84	74392	1496.57	32.5746.43	144092-86	1.90	15.28	0.44	4113488611	priest
84	74170	1226.05	32s746.43	144092.86	1.90	15.28	0.44	4113488611	priest
85	103665	18.51.43	156932.86	0.00	2.88	17.54	0.00	4054288529	priest
8 5	105224	2040.62	156932.86	0.00	2.88	17.54	0.00	4054288529	priest
86	107461	1596.55	254493.5?	36607.50	2.06	8.67	0.14	3656581462	priest
86	203534	982.28	176905.36	7900.71	2.07	17.24	0.04	3656581462	priest
87	48975	183.73	219407.14	32883.57	2.99	12.62	0.15	5533314176	priest
87	49769	239.42	219407.14	32883.57	2.99	12.62	0.15	5533314176	priest
8?	49331	173.44	219407.14	32883.57	2.99	12.62	0.15	55333141?6	priest
87	487%	241.00	219407.14	32883.57	2.99	12.62	0.15	5533314176	priest
87	49551	62.05	22is241.43	32940.00	3.00	12.54	0.15	5533314176	priest
87	48943	98.84	220241.43	32340.00	3.00	12.54	0.15	5533314176	priest
87	49511	81.22	220241.43	32940.LX3	3.00	12.54	0,15	5533314176	priest
87	48995	87.28	158191.07	275.36	2.96	15.22	0.00	5533314176	priest
87	201779	502.88	106301.43	0.00	3.-$8	19.44	0.00	5533314176	priest
8 8	196221	100.44	123644.29	0.00	3.55	18.75	0. 00	5579469121	priest
89	201608	264.92	11042.5.36	0.00	3.55	18.31	0.00	5884447497	priest
77	135781	127.82	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
78	143182	58.94	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
79	73872	43.72	216338.56	46336.32	2.72	15.65	0.16	4314068926	gray s
79	7635	5.98	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
79	68115	45.95	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
79	92258	74.87	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempt	spill.ratio	tonnage	hatchery
79	23402	69.92	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
80	37456	82.08	216338.56	46336.32	272	15.65	0.16	4314068926	grays
81	10180	34.41	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
81	64096	123.79	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
82	27460	6.55	216338.56	46336.32	272	15.65	0.16	4314068W6	grays
82	45361	25.23	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
83	97135	340.33	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
85	52090	1498.08	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
85	52368	1510.03	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
86	49874	123.16	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
86	50635	109.81	216338.56	46336.32	2.72	15.65	0.16	4314068926	gays
89	98541	32.02	216338.56	46336.32	2.72	15.65	0.16	4314068926	grays
79	32745	897.03	216338-56	46336.32	2.72	15.65	0.16	4314068926	brights
80	49334	487.91	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
80	100717	865.92	216338.56	46336.32	2.72	15.65	0.16	43140689-6	brights
81	99632	693.05	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
81	102221	1296.48	216338.56	.$6336.32	2.72	15.65	0.16	4314068926	brights
82	50553	1339.55	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
82	105029	467.83	216338-56	46336.32	2.72	15.65	0.16	4314068926	brights
82	104966	649.45	216338.56	46336.32	2.72	15.65	0.16	4314068W6	brights
83	49918	980.16	216338.56	46336.32	2.72	15.65	0.16	-$314068926	brights
83	9957(3	161.49	216338.56	46336.32	2.72	15.65	0.16	43140689'26	brights
83	100244	997.86	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
83	100259	782.27	216338.56	.$6336.32	2.72	15.65	0.16	4314068926	brights
83	99001	1470.34	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
84	210441	1634.69	216338.56	46336.32	2.72	15.65	0.16	4314068?Z6	brights
84	102184	2572.24	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
84	96448	73.75	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
84	101431	1819.16	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
85	78962	2398.68	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
85	206756	1787.91	216338.56	46336.32	2.72	15.65	0.16	4314068W6	brights
85	51960	1208.71	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
87	.$7943	2233.89	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights"
88	53333	37.06	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
89	51181	54.25	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
89	50424	54.43	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
89	49742	71.39	216338.56	46336.32	2.72	15.65	0.16	4314068926	
89	24352	246.53	216338.56	46336.32	2.72	15.65	0.16	4314068926	brights
78	146001	529.30	216338.56	46336.32	272	15.65	0.16	4314068926	cowlitz
80	244267	362.91	21633856	46336.32	272	15.65	0.16	4314068926	cowlitz

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempt	spill. ratio	tonnage	hatchery
80	70474	101.19	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
81	20719	395.22	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
81	153216	866.79	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
8 1	121271	326.12	216338.56	46336.32	2.72	15.65	0.16	43140689.6	cowli tz
82	41295	23.38	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
82	199176	423.14	216338.56	46336.32	2.72	15.65	0.16	43140689'26	cowli tz
83	150236	480.46	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
84	48946	476.53	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
84	49036	625.53	216338.56	46336.32	2.72	15.65	0.16	43140689-6	cowli tz
84	48829	450.95	216338.56	.46336.32	2.72	15.65	0.16	4314068926	cowlitz
84	49664	477.22	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowli tz
85	48634	582.31	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
85	48246	549.3-	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
85	48382	532.35	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
85	44126	644.41	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
8 6	197500	550.27	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowli [Z
87	207003	317.53	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
8 8	205308	97.10	216338.56	46336.32	2.72	15.65	0.16	4314068926	cowlitz
89	206145	205.16	216338.56	46336.32	2.72	15.65	0.16	4314068$26	cowlitz
77	126007	203 I .49	216338.56	46336.32	2.72	15.65	0.16	4314068W6	washougal
78	151399	5%.64	216338.56	46336.32	2.72	15.65	0.16	4314068'Z6	washougal
80	314605	1154.67	216338.56	-$6336.3?	2.72	15.65	0.16	43140689776	washougal
81	278774	605.63	216338.56	46336.32	2.72	15.65	0.16	4314068926	washougal
82	170424	376.11	216338.56	46336.32	2.72	15.65	0.16	4314068!Z?6	washougal
83	101206	674.98	216338.56	46336.32	2.72	15.65	0.16	4314068926	washougal
84	101594	2163.75	216338.56	.$6336.3?	2.72	15.65	0.16	4314068926	washougal
84	100892	1377.31	216338.56	46336,32	2.72	15.65	0.16	-$314068926	washougal
85	5207-	701.47	216338.56	46336.32	2.72	15.65	0.16	4314068926	washougal
85	52725	580.88	216338.56	46336.32	2.72	15.65	0.16	4314068926	washougal
85	51408	126Q74	216338.56	46336.32	2.72	15.65	0.16	431U)6W?6	washougal
85	26173	661.55	216338.56	46336.32	2.72	15.65	0.16	4314068926	washougal
85	25 169	592.25	216338.56	46336.32	2.72	15.65	0.16	431406W-6	washougal
86	214371	808.00	21633836	46336.32	2.72	15.65	0.16	4314068926	washougal
87	207377	400.45	216338.56	46336.32	2.72	15.65	0.16	43140689-6	
88	213935	442-54	216338.56	46336.32	2.72	15.65	0.16	4314068926	washougal
77	183202	241.36	216338.56	46336.32	2.72	15.65	0.16	4314068Y26	tanner
79	9657s	577.51	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
79	95576	89.21	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
79	287916	877.74	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
79	15102	5.13	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempt	spill.ratio	tonnage	hatchery
80	50462	53.80	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
80	996	45.48	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
80	48052	52.07	216338.56	46336.32	2.72	[5.63	0.16	4314068W.6	tanner
80		30.09	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
80	121071	155.91	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	129961	344.75	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	75717	208.35	216338.56	46336.32	2.72	15.65	0.16	4314068W6	tanner
81	50805	119.79	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	51609	78.71	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	53235	81.58	216338.56	46336.32	2.72	15.65	0.16	4314068926	
81	51818	206.93	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	51044	19.85	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	50868	119.82	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
81	102827	442.39	216338.56	46336.32	2.72	15.65	0.16	4314068926	
82	105872	3'9.55	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
82	96798	87.40	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
82	51619	21.10	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
82	52452	7.60	?16338.56	46336.3?	2.72	15.65	0.16	.$314068926	tanner
82	52525	33.29	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
82	54106	14.09	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
82	100062	216.15	216338.56	46336.32	2.72	15.65	0.16	4314068$26	ann
83	37492	119.59	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
83	49999	286.83	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
83	50779	299.72	216338.56	.46336.32	2.72	15.65	0.16	4314068926	tanner
83	52615	178.82	216338.56	$5.336.32	2.-2	15.65	0.16	4314068926	
83	47369	157.58	216338.56	%336.32	2.72	15.65	0.16	4314068926	
84	80348	20.1 Q	216338.56	46336.31	2.72	15.65	0.16	4314068926	tanner
84	80046	46.42	216338.56	-$6336.32	2.72	15.65	0.16	4314068926	tanner
84	80138	69.64	216338.56	.$6336.32	2.72	15.65	0.16	4314068926	tanner
84	81282	38.26	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
85	78367	2626.60	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
85	78962	2398.68	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	9891	41.01	216338.56	46336.32	2.72	15.65	0.16	-$314068926	tanner
87	8820	44.30	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	10402	43.39	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	11176	38.84	216338.56	.%336 .32	2.72	15.65	0.16	4314068926	tanner
87	15042	36.40	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	15683	104.42	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	16258	87.21	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	15991	53.53	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempt	Spill. ratio	tonnage	hatchery
87	15551	63.87	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17933	80.94	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	15694	95.09	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	16050	67.41	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	16873	84.55	216338.56	46336.32	2.72	15.65	0.16	431406W.6	tanner
87	16940	44.29	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	17630	114.71	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	17252	93.43	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	16503	68.07	216338.56	46336.32	2.72	15.63	0.16	4314068926	
87	18859	77.24	216338.56	46336.32	2.72	15.65	0.16	4314068%6	tanner
87	16499	131.72	216338.56	46336.3’2	2.72	15.65	0.16	4314068926	
87	17880	130.15	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	19665	98.68	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17120	82.48	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	15791	61.50	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	18171	138.58	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	13911	102.09	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	16964	104.39	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	15677	104.33	216338.56	%336.3?	2.72	15.65	0.16	4314068926	tanner
87	17495	157.32	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17389	72.02	216338.56	45336.32	2.72	15.65	0.16	4314068926	tanner
87	17926	104.87	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17657	126.95	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17840	73.24	216338.56	.$6336.32	2.72	15.65	0.16	4314068926	tanner
87	16328	103.89	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18454	146.44	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18276	122.44	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18226	109.86	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	15460	61.33	216338.56	46336.32	2.72	15.65	0.16	4314068W6	tanner
87	17795	15233	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	18385	0.00	216338.S6	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18202	104.16	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18011	126.95	216338.56	.%336 .32	2.72	15.65	0.16	4314068926	tanner
87	18044	11435	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	1782?	170.56	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	18479	82.09	216338.56	46336.32	2.72	15.65	0.16	4314068W6	tamer
87	18229	145.88	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18546	61.20	216338.56	46336.32	2.72	15.65	0.16	4314068926	
87	18071	87.26	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17803	133.99	216338.56	46336.32	2.72	15.65	0.16	-$314068926	tanner

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempc	spill.ratio	tonnage	hatchery
87	18462	158.15	216338.56	46336.3?	2.72	15.65	0.16	4314068926	tanner
87	18302	115.64	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17844	126.13	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18087	109.93	216338.56	46336.32	2.72	15.65	0.16	4314Q68926	t anner
87	18434	153.26	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18707	202.38	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18796	170.85	216338.56	46336.32	2.72	15.65	0.16	4314068926	lamer
87	18824	166.55	216338.56	46336.32	2.72	15.65	0.16	4314068926	tamer
87	18087	150.79	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18302	129.73	216338.56	46336.32	2.72	15.65	0.16	431.4068926	tanner
87	18891	202.49	216338.56	46336.32	2.72	15.63	0.16	4314068926	tanner
87	18751	139.24	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18653	112.12	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	1 80%	15238	216338.56	.%336.32	2.72	15.65	0.16	4314068926	tamer
87	17821	188.23	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18970	161.41	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18757	175..$2	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	19008	126.83	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18261	136.92	216338.56	.46336 .32	2.72	15.65	0.16	4314068926	tanner
87	18233	17.$.35	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18532	139.50	216338.56	46336.32	2.72	15.65	0.16	4314068926	t anner
87	18755	201.61	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18278	176.50	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18063	105.31	216338.56	46336.32	2.72	15.65	0.16	431406W.6	tanner
87	18229	123.28	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17755	178.16	216338.56	46336.32	2.72	15.65	0.16	431406SW6	tanner
87	18676	205.07	216338.56	46336.32	2.72	15.65	0.16	4314068!326	tanner
87	I 8440	213.40	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18503	141.52	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18062	179.37	216338.56	46336.32	2.72	15.65	0.16	43140689?6	tanner
87	18868	144.33	216338.56	46336.32	2.72	15.65	0.16	431406W26	tanner
87	18721	211.73	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18711	170.28	216338.56	.$6336.3?	2.72	15.65	0.16	4314068926	tanner
87	18002	118.37	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17386	141.75	216338.56	46336.32	2.72	15.65	0.16	43140WZ6	tanner
87	19003	183.98	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18753	134.55	216338.56	46336.32	2.72	15.65	0.16	431406SW6	tanner
87	19007	168.49	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18536	145.(X3	21633836	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18112	142.35	21633S.56	46336.32	2.72	15.65	0.16	4314068926	tanner

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempt	spill. ratio	tonnage	hatchery
87	18930	194.54	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18726	226.74	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18309	182.66	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18529	112.43	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18312	110.09	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18298	127.25	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	17830	173.45	216338.56	46336.32	2.72	15.65	0.16	4314068926	tamer
87	18527	84.23	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
87	18083	161.91	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29480	13.04	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29001	21.34	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	30040	16.57	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	28954	20.07	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29510	12.28	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29867	14.22	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29952	7.23	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	30071	12.62	216338.56	-$6336.32	2.72	15.65	0.16	43140689-6	tamer
88	29821	17.15	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	30235	9.94	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29579	12.16	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29215	20.42	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29372	12.12	216338.56	46336.32	2.72	15.65	0.16	43 14068%6	tanner
88	29634	12.50	216338.56	4.6336.32	2.72	15.65	0.16	4314068926	tanner
88	29450	12.75	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29664	9.35	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29315	21.86	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29437	11.69	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29351	12.16	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29690	16.85	216338.56	46336.32	2.72	15.65	0.16	4314068926	tamer
88	29845	8.36	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29521	11.95	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29600	18.38	216338.56	46336.32	2.72	15.65	0.16	431406SW6	tanner
88	29739	12.58	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29400	23.72	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29872	11.03	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29517	1.00	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	30087	17.46	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29387	21.83	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	30006	8.89	216338.56	46336.32	2.72	15.65	0.16	4314068926	tamer
88	29853	12.08	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner

Table C7: (continued).

relyr	marked	obs.return	flow	spill	turb	tempt	spill.ratio	tonnage	hatchery
88	29503	16.48	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29305	20.52	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29493	28.65	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29813	4.15	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29794	15.65	216338-56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29484	18.15	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29602	14.33	216338.56	46336.32	2.72	15.65	0.16	4314068926	t anner
88	29477	7.60	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29648	8.09	?16338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29538	10.58	216338.56	46336.32	2.72	15.65	0.16	4314068!E6	tanner
88	29909	23.15	216338.56	46336.3?	2.72	15.65	0.16	4314068926	tamer
8S	30248	8.81	216338.56	45336.32	2.72	15.65	0.16	4314068926	tanner
88	30193	16.33	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29509	14.88	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	30249	11.36	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
S8	29622	22.66	216338.56	46336.3?	2.72	15.65	0.16	4314068926	tanner
88	30886	22-22	216338.56	.$6336.32	2.72	15.65	0.16	4314068926	tanner
88	28413	31.11	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29675	14.21	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29625	14.61	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29316	37.48	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29421	38.20	216338.56	46336.32	2.72	15.65	0.16	4314068926	tamer
88	29335	22.57	216338.56	6336.32	2.72	15.65	0.16	4314068926	tanner
88	29694	29.3-	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	2%85	31.67	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29344	26.32	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29474	50.78	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29394	45.41	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
88	29658	22.69	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
89	2%59	60.61	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
89	2%89	78.55	21633856	.$6336.32	2.72	15.65	0.16	4314068926	tanner
89	2%95	72.76	216338.56	%336.32	2.72	15.65	0.16	4314068926	tanner
89	30072	95.43	216338.56	46336.32	2.72	15.65	0.16	-$314068926	tanner
89	30026	80.79	2 16338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
89	30047	145.08	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
89	29737	16.05	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
89	29734	22.56	216338.56	46336.32	2.72	15.65	0.16	43140689'26	tanner
89	29721	19.38	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner
89	29391	42.21	216338.56	46336.32	2.72	15.65	0.16	4314068W6	tanner
89	29375	64.05	216338.56	46336.32	2.72	15.65	0.16	4314068926	tanner

Table C8: Tag codes of subyearling fall chinook releases used in this analysis.

Bonneville Brights Hatchery

071658	071660	071661	071735	071733	071734	072207	072141	072142	072506	072507
072143	072424	072426	072545	072548	072547	072741	072826	072827	072828	073124
073125	072829	073008	073126	073323	073326	073007	073317	074129	074309	074319
074320	073318	074254	074304	074963	075030	075033	073555	075408	075409	071416
071417	075521	075618	075619	071460	071461					

BonnevilleTannerCreek Hatchery

091605	071656	071659	071608	071613	071657	071842	071843	071914	071736	071913
072133	072134	072135	072136	072157	072138	072139	072156	072329	072341	072342
072343	072344	072345	072346	072358	072140	072363	072407	072408	072414	072415
072416	072417	072425	072546	072663	072701	072727	072728	072729	072730	073120
073121	073122	073123	073322	073323	232052	232053	232054	232055	232056	232057
232058	232059	232060	232061	232062	232063	232101	232102	232103	232104	232105
232106	232107	232108	232109	232110	232111	232112	232113	232114	232115	232116
232117	232118	232119	232120	232121	232122	232123	232124	232125	232126	232127
232128	232129	232130	232131	232132	232133	232134	232135	232136	232137	232138
232139	232140	232141	232142	232143	232144	232145	232146	232147	232148	232149
232150	232151	232152	232153	232154	232155	232156	232157	232158	232159	232160
232161	232162	232163	232201	232202	232203	232204	232205	232206	232207	232208
232209	232210	232211	232212	232213	232214	232215	232216	232217	232218	232219
232220	232221	232222	232223	232224	232225	232501	232502	232504	232507	232508
232511	232513	232514	232516	232519	232521	232522	232525	232526	232528	232531
232532	232535	232537	232S38	232541	232542	232544	232547	232549	232550	232552
232555	232556	232559	232561	232562	232601	232602	232604	232607	232608	232611
232613	232614	232616	232619	232621	232622	232625	232626	232628	232631	232632
232635	232637	232638	232641	232642	232644	232647	232649	232650	232652	232655
233111	233122	233135	233147	233159	233207	232802	232814	232826	232838	232850
074747	074749	074750	074752	074755	074756	074402	074404	075753	075754	075755
075756										

Cowlitz Hatchery

631802	631942	631951	632154	632159	632137	632156	632255	632032	632450	632462
632603	632503	632610	632327	632328	633019	633020	633124	633125	633235	633236
633237	633238	633448	633449	633450	633451	634108	634126	635231	635250	630452
634056	634526	635015								

Table C8: Tag codes of subyearling fall chinook releases used in this analysis.

Grays River Hatchery

130402	130807	131615	631603	631743	631646	631833	631937	631939	631859	632043
632340	632263	632458	632459	632237	633242	633243	633326	633327	633759	633760
630419	635537	635538	635541	634218	634220	635911	634227	634229	634615	634933

Washougal Hatchery

010206	*631641*	*631803*	*631938*	*631946*	*632153*	*632251*	*632148*	*632461*	*632238*	*632239*
632259	*633116*	*633117*	*633118*	*633119*	*633334*	*633335*	*633407*	*633408*	*633414*	*633415*
633416	*633433*	*633434*	*633827*	*633828*	*633829*	*633830*	*633831*	*633832*	*634113*	*634150*
635228	*635904*	*635621*	*634616*	*635040*	*635043*					

Priest Rapids Hatchery

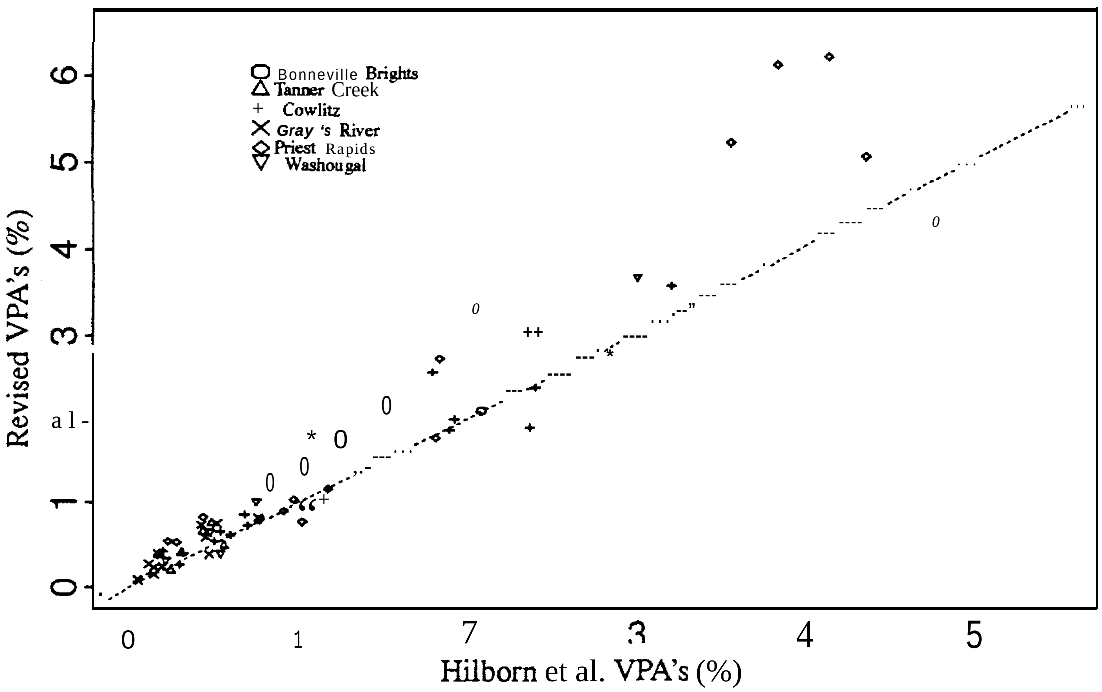
131101	131202	631662	631741	631821	631857	631958	632017	631948	632155	632261
632252	*632456*	*632611*	*632612*	*632848*	*632859*	*632860*	*633221*	*633222*	*632330*	*634102*
051915	*051916*	*051917*	*051918*	*051919*	*051920*	*051921*	*051922*	*634128*	*635226*	*635249*
630732	*634057*	*634341*	*635010*							

Appendix D: Plots of Daily River Conditions for Month Following Priest Rapid's Hatchery Releases

Table of Figures

Figure D 1 shows how the VPA's calculated prior to the CWT database update differ from those calculated afterwards. Most of the hatchery stock released had an estimated increase in percentage of released fish surviving to age 2, though Priest Rapids benefited more than those reference hatcheries used in this analysis.

Figure D 1: Comparison of VPA's estimated before and after CWT database update in November 1995.



Plots of river conditions and the least-squares regression line used in this analysis. Twenty-eight days after each Priest Rapid's release was used in regression to obtain an intercept and slope characterizing that particular set of river conditions the batch was subject to. The intercept represents initial conditions and the slope is the rate of change of those conditions. R^2 values were calculated and are displayed under each plot.

Figure D2: Plots of daily flows for the month following Priest Rapid's releases. Regressions lines summarize flows for the month.

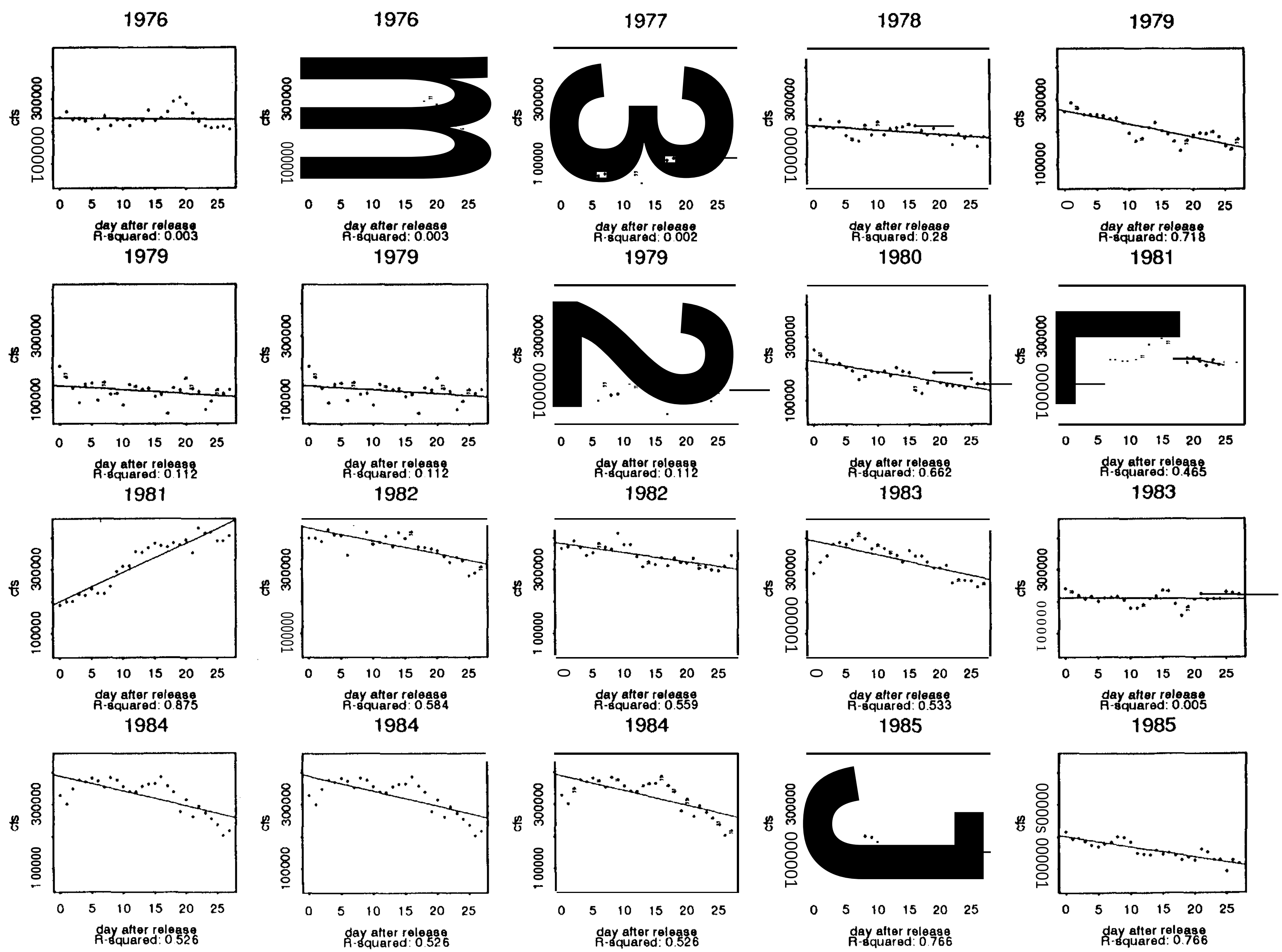


Figure D2: (continued)

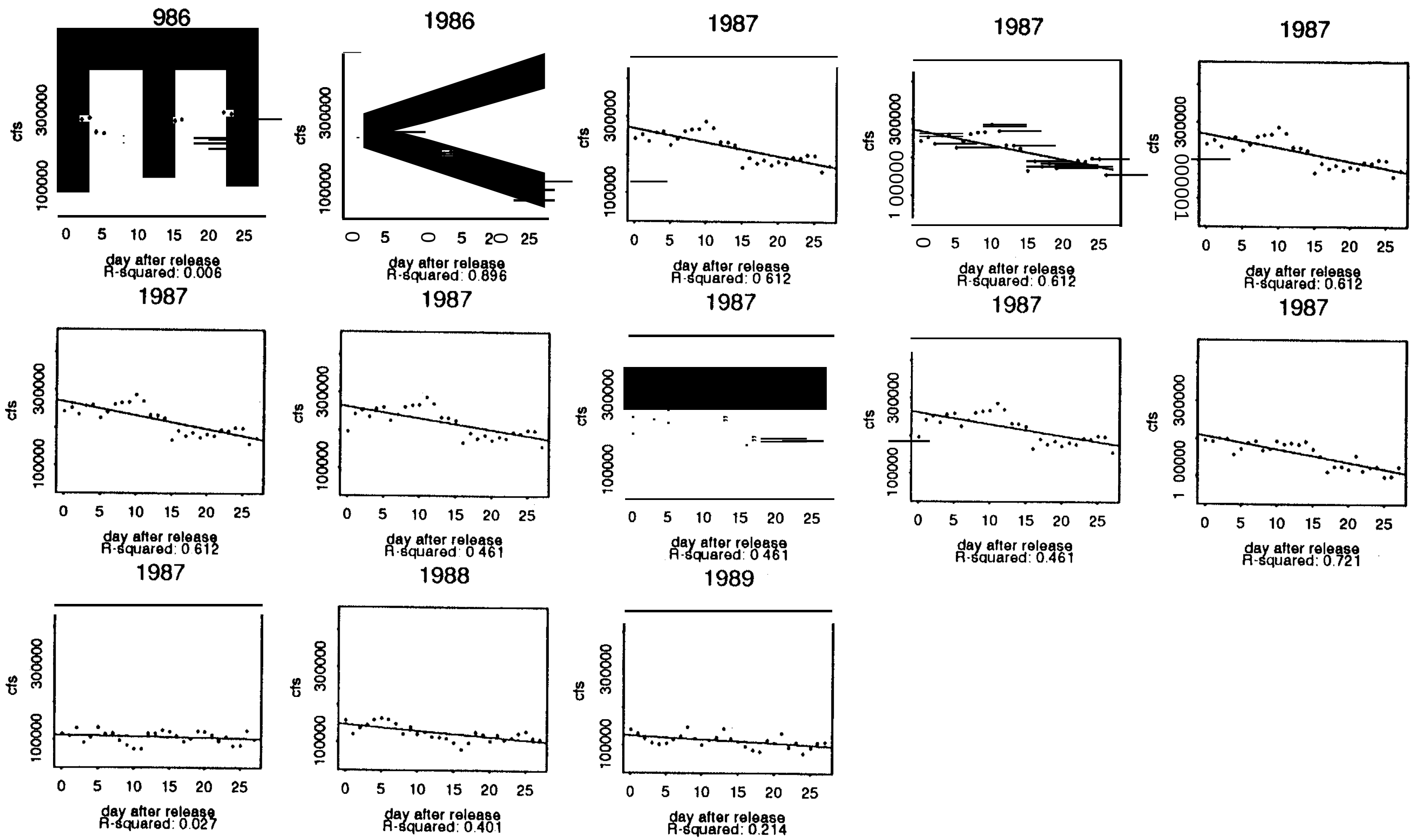


Figure D3: Plots of daily spill for the month following Priest Rapid's releases. Regressions lines summarize spill for the month.

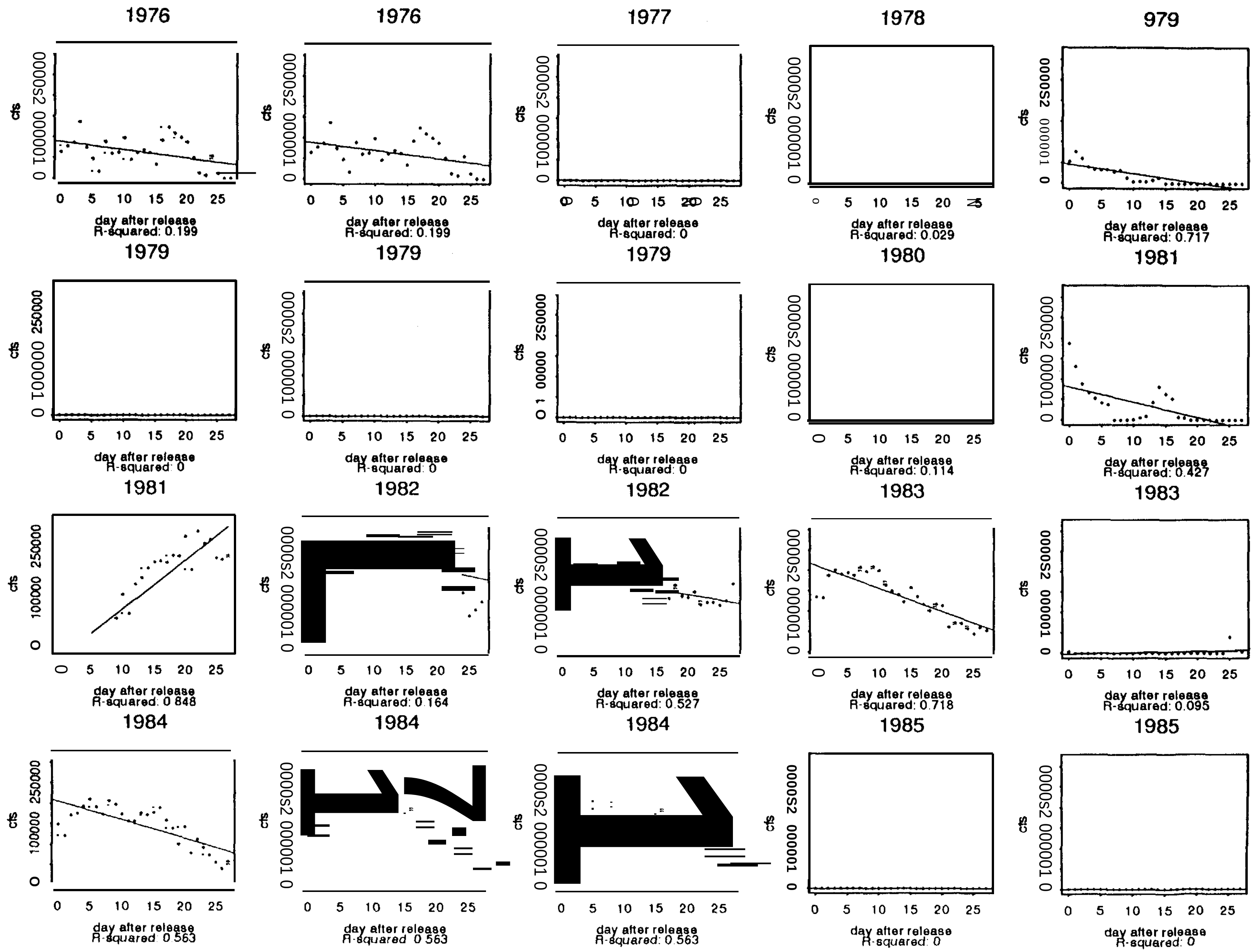


Figure D3: (continued)

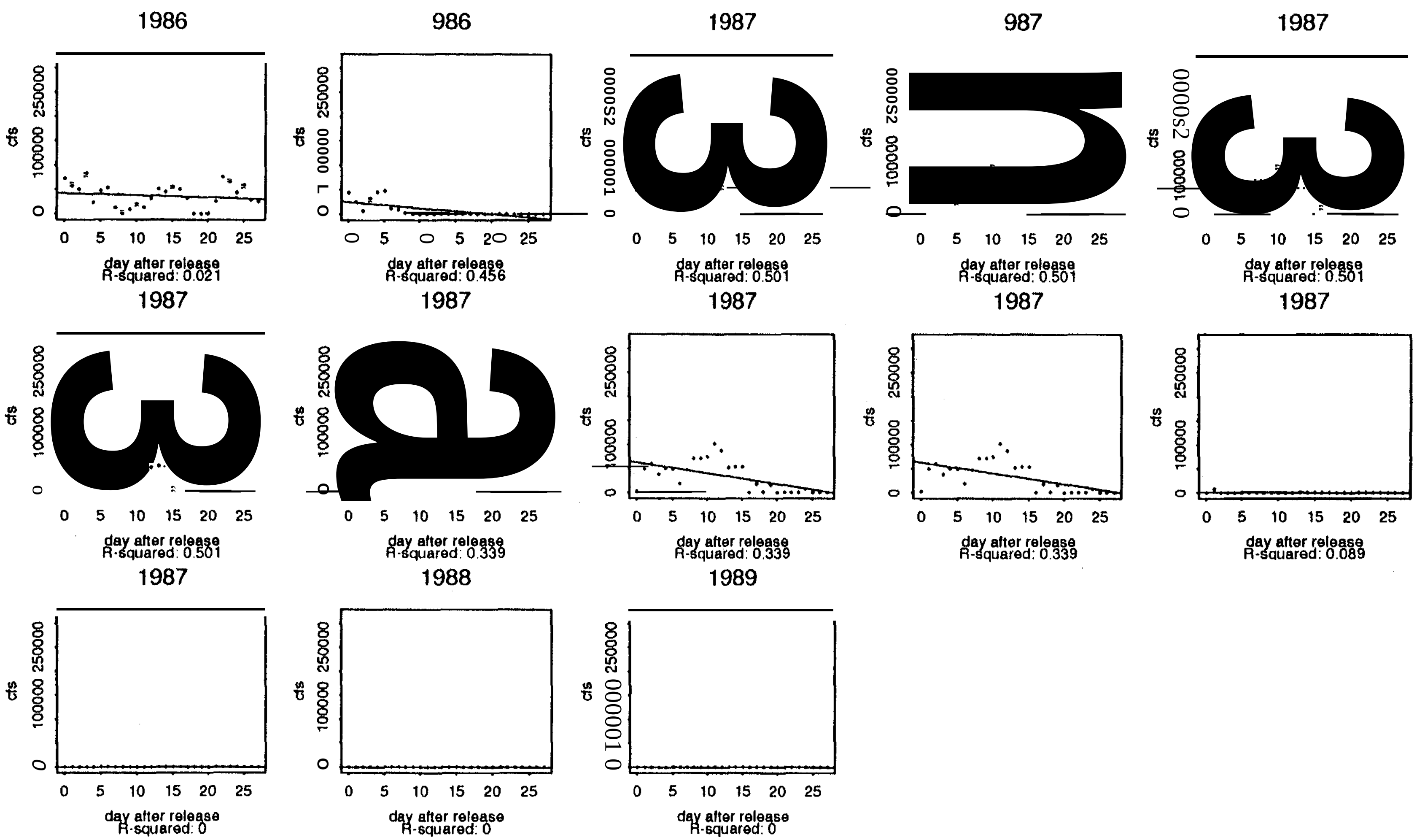


Figure D4: Plots of daily turbidity for the month following Priest Rapids releases.
Regressions lines summarize turbidity for the month.

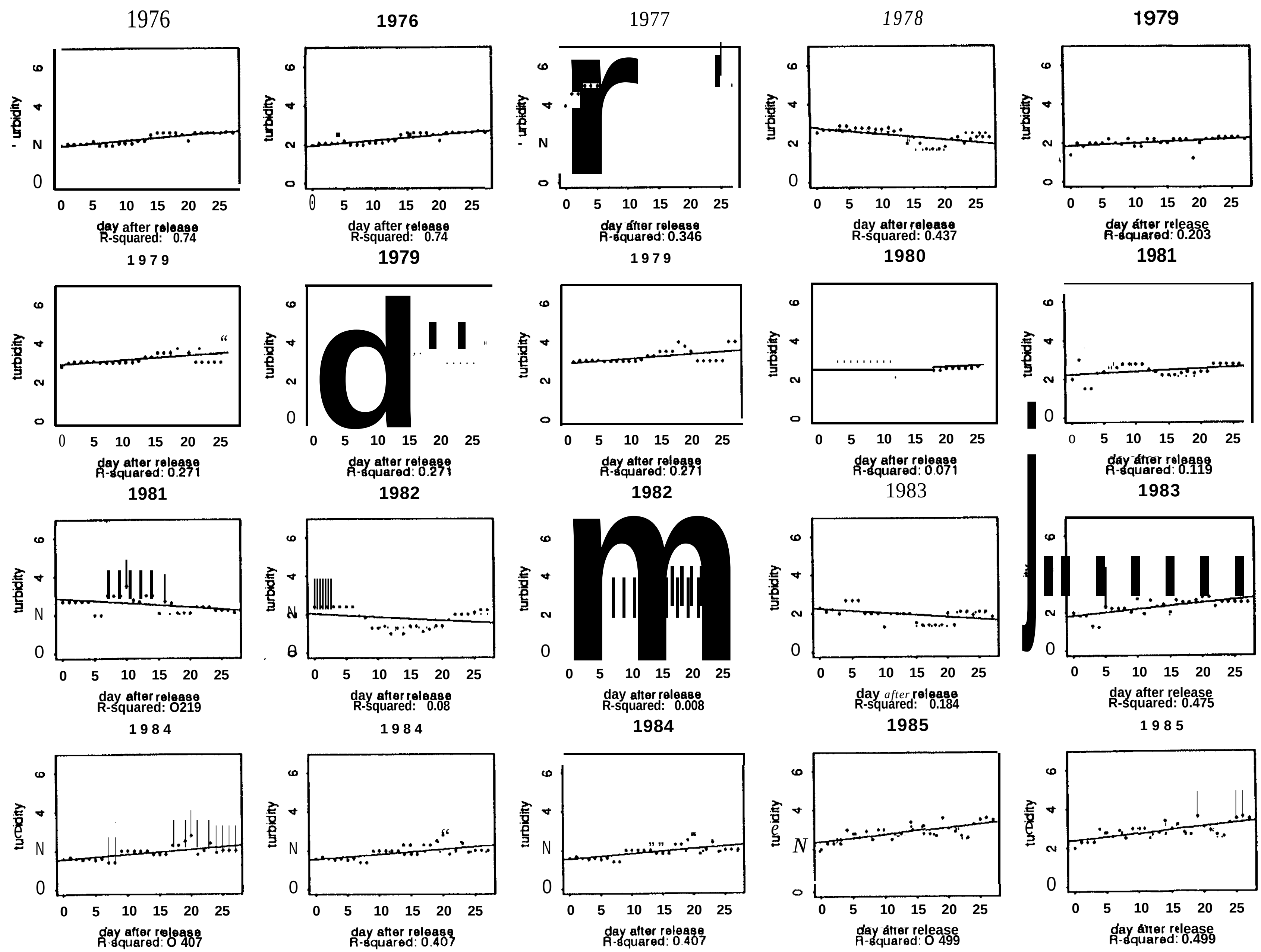
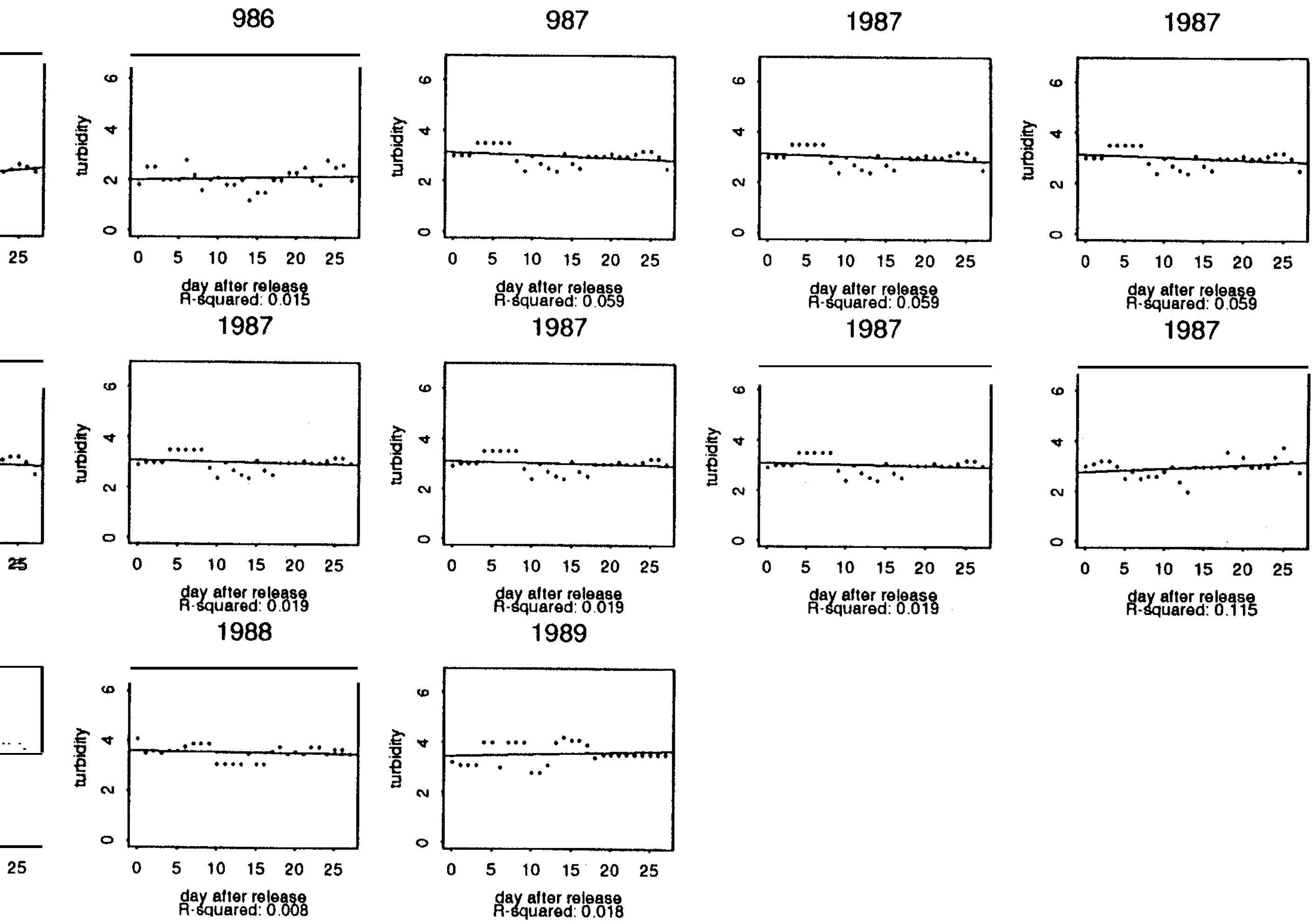


Figure D4: (continued)



: Plots of daily temperature for the month following Priest Rapid's releases.
Regressions lines summarize temperature for the month.

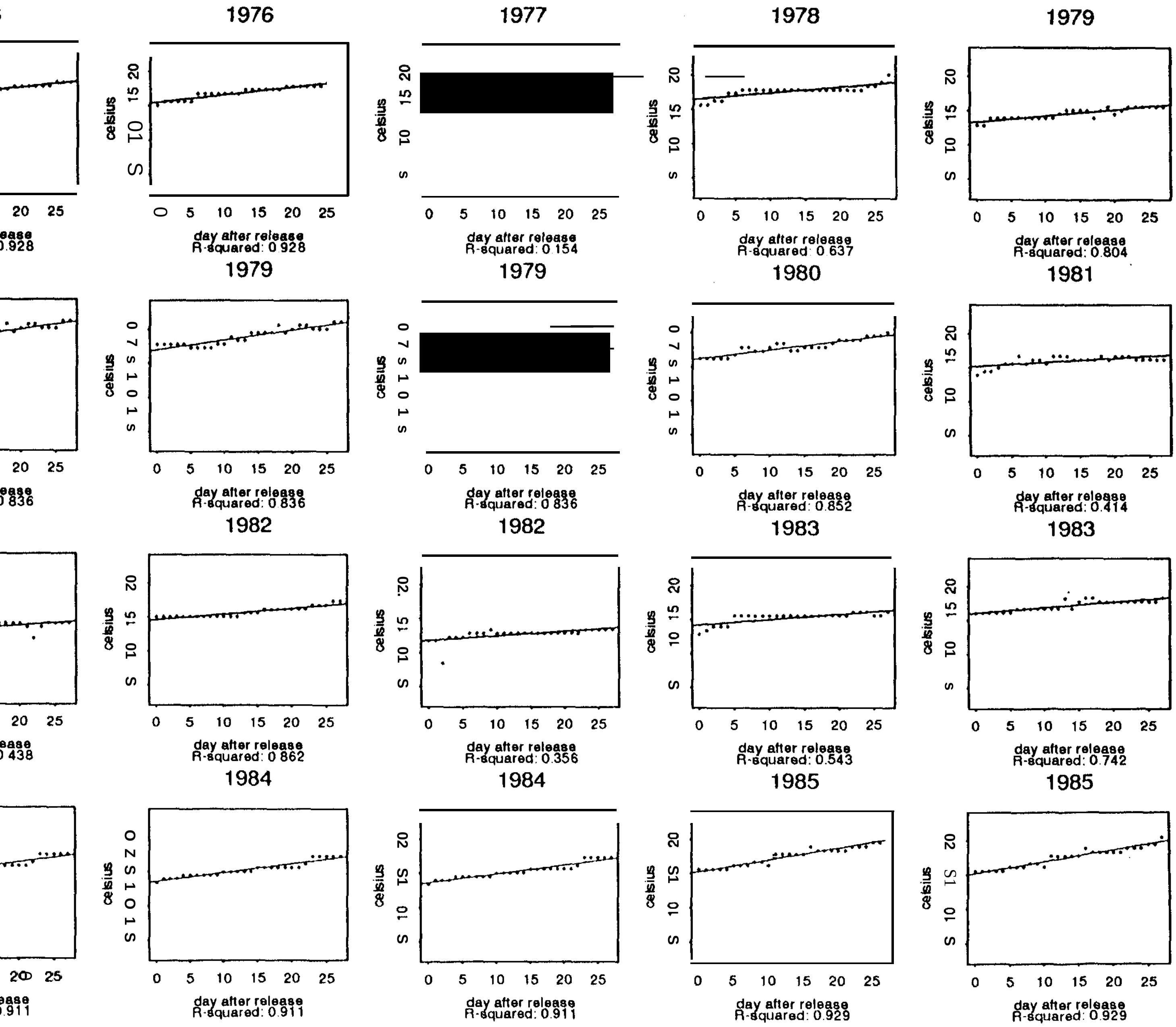
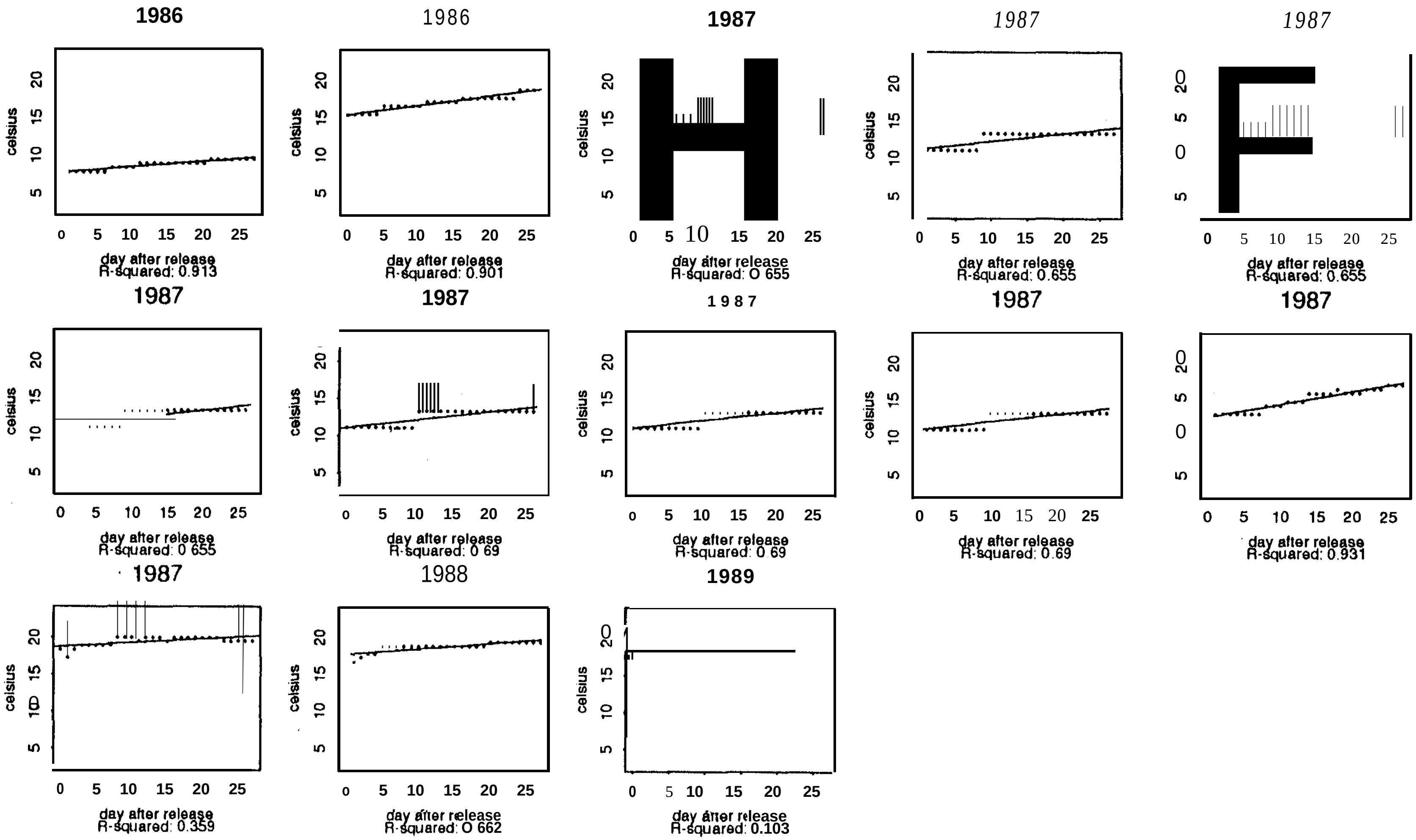


Figure D5: (continued)



Appendix E: ANODEV Tables **for Model (1)**

Table of Tables

Release year + *hatchery* is the basic model for the rest of the regressions presented in this section. Notice that these two variables explain approximately 70 percent of the variance seen in the survival rates.

Table El: Analysis of deviance tables for base model (l).

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	317	556.4877				
release year	13	351.9525	27.0733	40.2389	$< 1.0x10^{-16}$	0.6325
error	304	9334.5351	0.6728			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	317	556.4877				
hatchery	5	70.5931	1%1186	9.0658	$4.61x10^{48}$	0.1269
error	312	485.8946	1.5574			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	317	556.4877				
release year	13	351.9525				
hatchery	5	30.1358	6.0272	10.3333	3.73X1049	0.6866
$error_{base\ model}$	299	174.3993	0.5833			

Table E2: Analysis of deviance tables for *release year + hatchery + one river condition* at McNary Dam. R* values are for *base model+ river condition.*

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{base\ model}$	299	174.3993				
flow	1	11.0859	11.0859	20.2285	9.86×10^{-06}	0.7065
en-or	298	163.3135	0.S480			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{base\ model}$	299	174.3993				
spill	1	10.8316	10.8316	19.7338	1.26×10^{-05}	0.7061
error	298	163.5677	0.5489			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{base\ model}$	299	174.3993				
turbidity	1	12.7106	12.7106	23.4263	2.09×10^{-06}	0.7094
error	298	161.6887	0.5426			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{base\ model}$	299	17.$.3993				
temperature (C)	1	0.0018	0.00 18	0.0031	0.9s59	0.6866
-	298	174.3975	0.5852			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{base\ model}$	299	174.3993				
spill ratio	1	9.0525	9.0525	16.3151	0.0001	0.7029
error	298	165.3468	0.5549			

source	d.f	Deviance	Mean Dev.	F	p	R^2
$Total_{base\ model}$	299	174.3993				
hatchery contribution	1	19.6183	19.6183	37.?710	2.55×10^{-09}	0.7219
-	298	15.4.7811	0.5194			

Hatchery contribution is the most significant variable, but note that all except temperature have low p values ($p < 0.05$).

Table E3: Analysis of deviance tables for *release year + hatchery + two river conditions* at McNary Dam. The over-all model p value is the significance measure for both river conditions added to the base model *release year + hatchery*, not all four variables together.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution	I	19.6183			
flow	1	5.4509	5.4509	10.8413	0.0Q11
error	297	149.3301	0.502s		
over-all model p value					9.81x 10-11

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution	1	19.6183			
spiff	1	5.2793	5.2793	10.4878	0.0013
error	297	1.$9.5018	0.503-$		
over-d model p value					$1.16x10^{-10}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution	1	19.61S3			
turbidity	1	5.2862	5.2862	10.50?1	0. 0013
-	~9-	1-$9.4948	0.5033		
over-all model p value					$1.15x10^{-10}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	I 74.3993			
hatchery contribution	1	19.6183			
temperature (C)	1	1.2037	1.203 -	2.3279	0.12s1
error	W -	153.5 --3	0.51-1		
over-all model p value					$6.31x10^{-09}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution	1	19.6183			
spill ratio	1	5.0739	5.0709	10.0599	0.0017
-	297	149.7102 -	0.s04 1		
over-all model p value					1..$3X1OJJ

Again, all added river conditions except temperature are highly significant ($p < 0.05$). Flow is chosen as the next variable to include in the model, though spill, turbidity or spill ratio could as easily be considered.

Table E4: Analysis of deviance tables for *release year + hatchery + three river conditions* at McNary Dam. The over-all model p value is the significance measure for the three river conditions added to the base model *release year + hatchery*, not all five variables together.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution +flow	2	2S .0692			
spill	1	0.1805	0.1805	().3583	0.5499
error	296	1.49.1496	0.5039		
over-all model p value					-L73X1O"1*

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	17-$.3993			
hatchery contribution +flow	2	25.0692			
turbidity	1	0.58-3	0.5873	1.1687	0.2806
-	296	148.-42'?	0.5025		
over-all model p value					3.18×10^{-10}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{k\ model}$	299	174.3993			
hatchery contribution +flow	2	725.0692			
temperature (C)	1	0.5096	0.5096	1.0135	0.3149
error	296	148.S206	0.5028		
over-all model p value					3.43×10^{-10}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution +flow	2	25 .0692			
spill ratio	1	0.0321	0.0321	'00636	0,s011
-	296	149.298 I	0.5044		
over-all model p value					5.46×10^{-10}

No further information is gained by adding more river conditions to the regression. The best model is *log(observed returns/total released) = release year + hatchery + hatchery contribution + flow*.

One additional exercise was conducted with the following model: base model plus hatchery contribution plus one river condition plus flow. Spill, turbidity, temperature and spill ratio covariates were each inserted into the model (Table ES). The addition of any other covariate, with the exception of temperature, prior to flow appears to make the flow covariate nonsignificant ($p > 0.05$) to the model. This exercise simply confirmed that flow was highly correlated with most other river conditions.

Table ES: Analysis of deviance tables for release *year* + *hatchery* + *hatchery contribution* + *one river condition* + *flow* at McNary Darn. The over-all model p value is the significance measure for the three river conditions added to the base model *release year* + *hatchery*, not all five variables together.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution +spill	2	24.8976			
flow	1	0.3522	0.3522	0.6990	0.4038
error	296	149.14%	0.5039		
over-all model p value					4.73×10^{-10}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution + turbidity	2	24.9045			
flow	1	0.7520	0.7520	1.4964	0.2222
error	296	148.7429	0.5025		
over-all model p value					3.18×10^{-10}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution + temperature (C)	2	20.8220			
flow	1	4.7568	4.7568	9.4611	().00?3
error	296	148.8206	0.5028		
over-all model p value					3.43×10^{-10}

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	174.3993			
hatchery contribution + spill ratio	2	24.6892			
flow	1	0.4121	0.4121	0.8170	0.3668
-	296	149.2981	0.5044		
over-all model p value					5.46×10^{10}

Appendix F: ANODEV Tables for Model (2)

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Release year + hatchery is the basic model for the rest of the regressions presented in this section. Notice that these two variables explain approximately 68 percent of the variance seen in the survival rates.

Table F1: Analysis of deviance tables for base model (2), adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	31-	547.8629				
release year	13	341.8419	26.2955	38.8011	$< 1.0x10^{-16}$	0.6240
error	304	206.0209	0.6777			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	31-	547.8619				
hatchery	5	59.2985	11.8597	7.5737	$9.90x10^{-07}$	0.1082
error	312	488.564-$	1.5659			

Source	d.f.	Deviance	Mean Dev.	F	p	R
$Total_{corr}$	317	547.8629				
release year	13	341.8419				0.6765
+ hatchery	5	28.7870	5.7574	9.7129	1.31X1048	
$error_{base}$ model	299	177.2339	0.5928			

Table F2: Analysis of deviance tables for release *year* + *hatchery* + *one river condition* at McNary Dam.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{base model}}$	299	177.2339				
flow	1	13.8247	13.8247	75.2113	8.86×10^{-07}	0.7017
error	298	163.-$092	0.5484			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{base model}}$	299	177.2339				
spill	1	13.82S2	13.8282	25.2182	8.83×10^{-07}	0.7017
error	298	163.4057	0.S483			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{base model}}$	299	177.2339				
turbidity	1	14.5907	14.5'X%	26.7335	4.29×10^{-07}	0.7031
error	298	162.6432	0.5458			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{base model}}$	299	177.2339				
temperature (C)	1	0.0149	0.0149	0.0251	0.8742	0.6765
error	298	177.2190	0.5947			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{base model}}$	299	1-7.2339				
spill ratio	1	11.7868	11.7868	21.2301	6.05×10^{-06}	0.6980
error	298	165.4-$'1	0.5552			

source	d.f	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{base model}}$	299	1-7.2339				
hatchery contribution	1	20.4462	20.4462	38.X612	1.55X1049	0.-138
error	298	156.7878	0.5261			

Hatchery contribution is the most significant variable, but note that all except temperature have low p values (p c< 0.05).

Table F3: Analysis of deviance tables for *release year + hatchery + two river conditions* at McNary Dam. The over-all model p value is significance measure for both river conditions added to the base model *release year + hatchery*, not all four variables together.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	1?7.2339			
hatchery contribution	1	20.4462			
flow	1	7.3559	7.3559	14.6200	0.0002
error	297	149.4319	0.5031		
over-all model p value					$9.90x10^{-12}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	177.2339			
hatchery contribution	1	20.4462			
spill	1	7.3721	7.3721	14.6537	0.0002
error	297	149.4157	0.5031		
over-all model p value					$9.74x10^{-12}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	177.2339			
hatchery contribution	1	20.-$-$62			
turbidity	1	6.4352	6..4352	12.7119	0.0004
error	297	150.3525	0.5062		
over-all model p value					$2.46x10^{-11}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	177.2339			
hatchery contribution	1	20.4462			
temperature (C)	1	1.6662	1.6662	3.1902	0.0:51
-	297	155.1215	0.5223		
over-all model p value					$2.54x10^{-09}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	177.2339			
hatchery contribution	1	20.4462			
spill ratio	1	7.1100	7.1100	1-$.1081	0.0002
error	297	149.6777	0.5040		
over-all model p value					$1.26x10^{-i]}$

Again, all added river conditions except temperature are highly significant ($p < 0.05$). Spill is chosen as the next variable to include in the model, though flow, turbidity or spill ratio could as easily be considered.

Table F4: Analysis of deviance tables for *release year* + *hatchery* + *three river conditions* at McNary Dam. The over-all model p value is significance measure for the three river conditions added to the base model *release year* + *hatchery*, not all five variables together.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	177.2339			
hatchery contribution +spill	2	27.8182			
flow	1	0.3478	0.3478	0.6907	0.4066
error	296	149.0679	0.5036		
over-all model p value					$4.19x10^{-11}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	177.2339			
hatchery contribution +spill	2	27.8182			
turbidity	1	1.3003	1.3003	2.5986	0.1080
error	296	148.1154	0.5004		
over-all model p value					$1.65x10^{-11}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{base\ model}$	299	1--.2339			
hatchery contribution +spill	2	27.8182			
temperature (C)	1	0.0081	0.0081	0.0160	0.8993
error	296	14940-6	0.5048		
over-all model p value					$5.84x10^{-11}$

No further information is gained by adding more river conditions to the regression. The best model is *log(observed returns/total released) = release year + hatchery + hatchery contribution + spill.*

Appendix G: ANODEV Tables for Model (3)

Table of Tables

Table G 1: Analysis of deviance tables for Grays River references, using single river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.7713				
flow.a + flow.b[a]	2	4.8690	2.4345	2.6267	0.1052	0.2694
error	15	13.9023	0.9268			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.7713				
spill.a + spill.b	2	'4.0949	2.0474	2.0926	0.1579	0.2181
error	15	14.6765	0.9784			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.7713				
turb.a + turb.b	?	4.7406	?.3703	2.5341	0.1127	0.2525
-	15	14.0307	0.9354			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	,-	18.713				
tempt.a + tempc.b	,	10.2587	5.1293	9.0383	0.0027	0.5465
-	15	8.512-	0.5675			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.7713				
spill ratio	1	4.1407	4.140:	4.5283	0.0492	0.2206
error	16	1.$.6306	0.9144			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.7713				
hatchery contribution	1	1.5229	1.5229	l.-r12-	0.2520	0.0811
-	16	17.2484	1.078			

a. "a" ending indicates the intercept, "b" indicates the slope of the linear regression for that variable

Table G2: Analysis of deviance tables for Grays River references using two river conditions at McNary Darn and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.7713			
tempt.a + tempt.b	2	10.2587			
spill.a + spill.b	2	0.7294	0.3647	0.6092	0.5586
-	13	7.7832	0.5987		
over-all model p value					0.0157

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.7713			
tempt.a + tempt.b	2	10.2587			
turb.a + turb.b	2	1.9323	0.9662	1.9087	().1876
error	13	6.5S0-!	0.5062		
over-all model p value					0.0057

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.7713			
tempt.a + tempc.b	2	10.2587			
flow.a + flow.b	~	1.1087	0.5544	0.9733	0..5037
error	13	7.4040	0.5695		
over-all model p value					0.0117

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.7713			
tempt.a + tempt.b	·	10.2587			
spill ratio	1	0.5474	0.5474	0.9620	0.3433
-	14	-.9653	0.5690		
over-all model p value					0.0062

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.7713			
tempt.a + tempt.b	2	10.2587			
hatchery contribution	1	1.0636	1.0636	1.9989	0.1793
-	14	7.4491	0.5321		
over-all model p value					0.0039

Table G3: Analysis of deviance table for Bonneville Brights references using single river conditions at McNary Darn and observed counts, unadjusted for the probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	61.5207				
flow.a + flow.b	2	14.5308	7.2654	3.7108	0.0394	0.2362
error	24	46.9899	1.9579			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	61.5207				
spill.a + spill.b	2	14.4427	7.2214	3.6814	0.(?403	0.2348
error	24	47.0780	1.%16			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{cOr}$	26	61.5207				
turb.a + turb.b	2	28.0382	14.0191	10.0488	0. OX)-	().4558
error	24	33,4825	1.3951			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	61.5207				
tempc.a + tempt.b	2	3.1(333	1.5802	0.6498	().531 1	0.0514
-	24	58.36(M	2.431-			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	61.520				
spill ratio	1	11.2267	11.226-	5.5806	().0263	0.1825
error	25	50.2940	2.0118			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	61.5207				
hatchery contribution	1	19.3527	19.3527	11.4736	().(X)22	().3146
-	25	42.1679	1.6867			

Table G4: Analysis of deviance table for Bonneville Brights references using two river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	61.5207			
turb.a + turb.b	2	28.0382			
flow.a + flow.b	2	4.4772	2.2386	1.6979	0.2062
error	22	?9.0053	1.3184		
over-all model p value					0.0017

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	61.5207			
turb.a + turb.b	2	28.0382			
spill.a + spill.b	2	4.8463	2.4232	1.8616	0.17?1
error	22	28.6362	1.3016		
over-all model p value					0.0015

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	61.5207			
turb.a + turb.b	2	28.0382			
tempt.a + tempt.b	2	8.699	4..3495	3.861	0.0365
-	22	24.7835	1.1265		
over-all model p value					0.0003

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	61.5207			
turb.a + turb.b	2	2S.0382			
spill ratio	1	0.4635	0.4635	0.3229	0.5ˉ54
-	23	33.0190	1.4356		
over-all model p value					0.0022

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	61.5207			
turb.a + turb.b	2	28.0382			
hatchery contribution	1	0.5881	0.58S 1	0.4112	(),5~7-
-	23	32.894.4	1.4302		
over-all model p value					0.0021

Table G5: Analysis of deviance tables for Bonneville Brights references using three river conditions at McNary Darn and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
Total_{corr}	26	61.5207			
turb.a + turb.b + tempt.a + tempc.b	4	36.7372			
spill.a + spill.b	2	3.5370	1.7685	1.6648	0.2144
error	20	21.2465	1.0623		
over-all model p value					0.01X)8

Source	d.f.	Deviance	Mean Dew.	F	p
Total_{corr}	26	61.5207			
turb.a + turb.b + tempt.a + tempc.b	4	36.7372			
flow.a + flow.b	2	3.0134	1..5067	1.3842	0.2735
error	20	21.7701	1.0885		
over-all model p value					0.0009

source	d.f.	Deviance	Mean Dev.	F	p
Total_{corr}	26	61.5207			
turb.a + turb.b + tempc.a + tempt.b	4	36.7372			
spill ratio	1	0.6784	0.6784	0.5910	0.4506
error	21	24.1051	1.1479		
over-all model p value					0.0008

source	d.f.	Deviance	Mean Dev.	F	p
Total_{corr}	26	61.5207			
turb.a + turb.b + tempt.a + tempc.b	4	36.7372			
hatchery contribution	1	0.0150	0.0150	0.0127	0.9112
-	21	24.7685	1.1795		
over-all model p value					0.0011

Table G6: Analysis of deviance tables for Cowlitz references using single river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	7.9715				
flow.a + flow.b	2	0.9834	0.4917	1.6183	0.2200	0.1234
error	23	6.9881	0.303 s			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	7.9715				
spill.a + spill.b	?	0.4.973	0.2486	0.7651	0.4768	0.0624
error	23	7.4742	0.32S0			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	7.9715				
turb.a + turb.b	·	1.4764	0.7382	2.6142	0.0948	0.1852
error	23	6..$951	0.2824			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	7.9715				
tempt.a + tempc.b	2	0.6414	0.3207	1.0063	0.3811	0.0805
error	23	7.330 I	0.3187			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	7.9715				
spill ratio	1	0.4387	0.4387	1.39--	0.2487	0.0550
error	24	7.5328	0.3139			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	7.9715				
hatchery contribution	1	0.8586	0.8586	2.8972	0.1017	0.1077
error	24	7.1129	0.2964			

Table G7: Analysis of deviance tables for Cowlitz references using two river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	7.9715			
turb.a + turb.b	2	1.4764			
flow.a + flow.b	2	0.3404	0.1702	0.5808	0.5682
error	21	6.1546	o.~931		
over-all model p value					0.2244

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	7.9715			
turb.a + turb.b	2	1.4764			
spill.a + spill.b	2	0.1282	0.0641	0,Q115	0.8111
-	21	6.3668	0.3032		
over-all model p value					0.2940

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	7.9715			
turb.a + turb.b	[illegible]	1.4764			
tempc.a + tempt.b	[illegible]	0.8015	0.-lore	1.4780	0.2509
-	21	5.6936	0.2:11		
over-all model p value					0.1168

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	?5	7.9715			
turb.a + turb.b	2	1.4:6-1			
spill ratio	1	0.0275	0.0275	0.0936	0.7625
-	22	6.4675	0. 2940		
over-all model p value					0.1951

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	7.9715			
turb.a + turb.b	2	1.4764			
hatchery contribution	1	0.0048	0.0048	0.0162	0.9000
error	22	6.4903	0.2950		
over-all model p value					0.2017

Table G8: Analysis of deviance tables for Washougal references using single river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	11.8235				
flow.a + flow.b	2	4.3688	2.1844	6.7395	0.0050	0.3695
-	23	7.4547	0.3241			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	11,8235				
spill.a + spill.b	?	2.2744	1.1372	2.7391	0.0857	0.19?24
error	23	9.5491	0.4152			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	11.8235				
turb.a + turb.b	·	2.9972	1.4986	3.9351	0.0347	0.2535
error	23	8.S263	0.3838			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	11.8235				
tempt.a + tempt.b	?	2.9096	1.4548	3.7538	0.0388	0.2461
-	23	8.9139	0.3876			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	11.8235				
spill ratio	1	1.4511	1.4511	3.3577	0.0793	0. [227
-	24	10.3724	0.4322			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	11.8235				
hatchery contribution	1	0.5375	0.5375	1.143	0.2957	0.0455
error	24	11.2860	0.4702			

Table G9: Analysis of deviance tables for Washougal references using two river conditions at McNary Darn and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mesrr Dev.	F	p
$Total_{corr}$	2s	11.8235			
flow.a + flow.b	2	%36S8			
spill.a + spill.b	2	1.8299	0.9150	3..4159	0.0520
error	21	5.6248	0.26'78		
over-ail model p value					0.0027

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b	2	4.36S8			
turb.a + turb.b	2	0.8518	0.4259	1.3546	0.2797
error	21	6.6029	0.31.$4		
over-d model p value					0.0124

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b	2	4.3688			
tempc.a + tempc.b	2	0.6919	0.3460	1.0742	0,3596
-	21	6.7628	0.3220		
over-d model p value					0.0156

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b	2	4.3688			
spill ratio	1	1.9776	1.97?6	7.9437	0.0100
error	22	5.4771	0.2490		
over-all model p value					0.0006

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b	2	4.3688			
hatchery contribution	1	0.0167	0.0167	0.0495	0.8260
-	22	7.4380	0.3381		
over-all model p value					0.0153

Table G1O: Analysis of deviance tables for Washougal references using three river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b + spill ratio	3	6.3464			
turb.a + turb.b	2	0.0164	0.0082	0.0300	0.9705
en-or	20	5.4607	0.2730		
over-all model p value					0.0055

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b + spill ratio	3	6.3464			
tempc.a + tempt. b	2	0.3177	0.1588	0.6158	0.5501
-	20	5.1593	0.2580		
over-all model p value					0.0033

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	11.8235			
flow.a + flow.b + spill ratio	3	6.3464			
hatchery contribution	1	0.0128	0.0128	0.0492	0.8266
error	21	5.4643	0.2602		
over-all model p value					0.0020

Table G11: Analysis of deviance tables for Tanner Creek references using single river conditions at McNary Darn and observed counts, unadjusted for the probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	68.6817				
flow.a + flow.b	2	24.4271	12.2136	6.8996	0.0341	0.3557
error	25	.$4.2546	1.7702			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	68.6817				
spill.a + spill.b	2	27.8558	13.92-9	8.5288	0. 0015	0.4356
error	25	40.8259	1,6330			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	68.681:				
turb.a + turb.b	?	23. j--j	11.:888	6.5342	0.0052	0.3433
error	25	45.10$1	1.8042			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	68.6817				
tempt.a + tempc. b	2	1.7408	0. 8704	0.3251	0.-255	0.0253
-	25	66.9409	2.6776			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	68,681 -				
spill ratio	1	25.8368	25.8368	15.6788	0.0005	0.3762
-	26	42.8449	1.6479			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	68.681 -				
hatchery contribution	1	23.7957	21795-	13.835	0.0010	0.3465
-	26	44.8860	1.7264			

Table G12: Analysis of deviance tables for Tanner Creek references using two river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	68.6817			
spill ratio	1	25.8368			
flow.a + flow.b	2	0.0995	0.0498	0.02?9	0.9725
error	24	42.7454	1.7811		
over-all model p value					0.0089

Source	d. f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	68.6817			
spill ratio	1	25.8368			
turb.a + turb.b	2	18.7305	9.3652	9.3208	0.0010
error	24	24.1144	1.0048		
over-all model p value					$1.16x10^{-05}$

Source	d.f.	Deviance	Meao Dev.	F	p
$Total_{corr}$	~-	68.681:			
spill ratio	1	25.8368			
tempt.a + tempt. b	·	10.3112	5.1556	3.8033	0.0367
error	24	32.5336	1.3556		
over-al model p value					0.0004

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	~-	68.6817			
spill ratio	1	25.8368			
hatchery contribution	I	14.5298	1.$.5298	12.8287	0.0014
errs'	25	283151	1.1326		
over-all model p value					1.55X1045

Table G13: Analysis of deviance tables for Tanner Creek references using three river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	68.6817			
spill ratio + turb.a + turb.b	3	44.5673			
flow.a + flow.b	2	1.4559	0.7280	0.7068	0.5041
error	22	22.6585	1.0299		
over-all model p value					0.030 I

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	68.6817			
spill ratio + turb.a + turb.b	3	44.5673			
tempt.a + tempc.b	2	8.5874	4.2937	6.0837	0.0079
-	22	15.5270	0.7058		
over-all model p value					1.79×10^{-06}

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{wm}$	27	68.681:			
spill ratio + turb.a + turb.b	3	44.5673			
hatchery contribution	1	2.5-$82	2.5482	2.- I-6	0.1128
error	23	21.5663	0.93--		
over-all model p value					1 46110')5

Table G 14: Analysis of deviance tables for Tanner Creek references using four river conditions at McNary Dam and observed counts, unadjusted for the probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	68.6817			
spill ratio+ turb.a + turb.b + tempt.a + tempt. b	5	53.1547			
flow.a + flow.b	2	0.6839	0.3419	0.4608	0.6373
-	20	14.8431	0.7422		
over-ail model p value					$I.83x10^{45}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	68.6817			
spill ratio + turb.a + turb.b + tempc.a + tempc.b	5	53.1547			
hatchery contribution	1	0.4875	0..$875	0.6807	0.4186
error	21	15.0395	0.7162		
over-all model p value					$5.46x 10^{-06}$

Appendix H: ANODEV Tables for Model (4)

Table HI: Analysis of deviance tables for Grays River references, using single river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4555				
flow.a + flow.b	2	6.5468	3.2734	3.5303	0.0554	0.3201
error	15	13.9087	0.9272			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4555				
spill.a + spill.b	2	5.7999	2.9000	2.9681	0.0820	0.2835
error	15	14.6557	0.9770			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4555				
turb.a + turb.b	2	5.9286	2.9643	3.0608	0.0768	0.2898
error	15	14.5269	0.%85			

Source	d.f.	Deviants	Mean Dev.	F	p	R^2
$Total_{corr}$	1-	20.4555				
tempt.a + tempt.b	2	11.31%	5.6598	9.2926	0.0024	0.5534
-	15	9.1359	0.6091			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4555				
spill ratio	1	5.8557	5.8557	6.41:3	0.0221	0.2863
error	16	14.5998	0.9125			

source	d.f.	De. iance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4555				
hatchery contribution	1	1.5692	1.5692	1.3294	0.2659	0.0767
m	16	18.8864	1.1804			

TableH2: Analysis of deviance tables for Grays River references using two river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4555			
tempt.a + tempt.b	2	11.3196			
spill.a + spill.b	2	1.3667	0.6834	1.1435	0.3488
error	13	7.7692	0.5976		
over-all model p value					0.0093

soul-(x	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4555			
tempt.a + tempt.b	2	11.31%			
turb.a + turb.b	2	2.4364	1.2182	2.3638	0.1332
error	13	6.6996	0.5154		
over-all model p value					0. 0038

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4555			
tempt.a + tempt.b	2	11.31%			
flow.a + flow.b	2	1.7646	0.8823	1.5561	0.2478
error	13	7.3713	0..5670		
over-all model p value					0,0068

source	d.f.	Deviance	Mean Dev	F	p
$Total_{corr}$	17	20.4555			
tempt.a + tempt.b	2	1131%			
spill ratio	1	1.1360	1.1364)	1.9881	(). I no-l
error	14	7.9999	0.5-14		
over-all model p value					0.(X)36

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4555			
tempt.a + tempt.b	2	11.31%			
hatchery contribution	1	1.0692	1.0692	1.8556	0.194-
-	14	8.0658	0.5762		
over-all model p value					0.0038

TableH3: Analysis of deviance table for B onneville Brights references using single river conditions at McNary Darn and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	64.8502				
flow.a + flow.b	2	17.9034	8.9517	4.5763	0.0207	o,~761
error	24	46.9468	1.9561			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	64.8502				
spill.a + spill.b	2	18.0002	9.000 1	4.6105	0.0202	0.2776
error	24	46.8500	1.9521			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	64.8502				
turb.a + turb.b	2	30.7665	15.3832	10.8321	0.0004	0.4744
error	24	34.0837	1.4202			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	6$.8502				
tempt.a + tempt.b	2	2.9189	1.4594	0.5656	0.5754	0.0450
error	24	61.9313	2.5805			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	64.s502				
spill ratio	1	14.3855	14.3855	7.1265	0.0132	0.2218
erro?-	25	50.4647	2.0186			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	64.8502				
hatchery contribution	1	20.s245	20.8245	11.s252	0.0321	0.3211
-	2s	44.0257	1.7610			

TableH4: Analysis of deviance table for Bonneville Brights references using two river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	64.8502			
turb.a + turb.b	2	30.7665			
flow.a + flow.b	2	4.9386	2.4693	1.8640	0.1787
error	22	29.1451	1.3248		
over-all model p value					0.0011

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	64.8502			
turb.a + turb.b	2	30.7665			
spill.a + spill.b	2	5.5405	2.7702	2.1352	0.1421
error	22	28.5432	1,2974		
over-all model p value					0.001)9

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	64.8502			
turb.a + turb.b	2	30.7665			
tempc.a + tempt.b	2	8.7382	4.3691	3.7924	0.0384
error	22	25.3455	1.1521		
over-all model p value					0.0003

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	64.8502			
turb.a + turb.b	2	30.7665			
spill ratio	1	0.8375	0.837S	0.5794	0.4543
-	23	33.2462	1.4455		
over-all model p value					0.00I3

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	64.8502			
turb.a + turb.b	2	30.7665			
hatchery contribution	1	0.6296	0.6296	0.4329	0.5171
-	23	33.4541	1.45.55		
over-all model p value					0.0014

TableI-U: Analysis of deviance tables for Bonneville Brights references using three river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
Total$_{corr}$	26	64.8502			
turb.a + turb.b + tempt.a + tempt.b	4	39.5047			
spill.a + spill.b	2	4.1104	2.0552	1.9356	0.1704
error	20	21.235 1	1.0618		
over-all model p value					0.0005

Source	d.f.	Deviance	Mean Dev.	F	p
Total$_{corr}$	26	64.s502			
turb.a + turb.b + tempt.a + tempt.b	4	39.5047			
flow.a + flow.b	2	3.7038	1.8519	1.7114 ‘	0.2060
error	20	21.6417	1.0821		
over-all model p value					0.0005

Source	d.f.	Deviance	Mean Dev.	F	p
Total$_{corr}$	26	64.s502			
turb.a + turb.b + tempt.a + tempc.b	4	39.5047			
spill ratio	1	1.1208	1.1208	0.9716	0.3355
error	21	24.2247	1.1536		
over-all model p value					0.0005

source	d.f.	Deviance	Mean Dev.	F	p
Total$_{corr}$	26	64.8502			
turb.a + turb.b + tempc.a + tempc.b	4	39.5(M7			
hatchery contribution	1	0.0169	0.0169	.0.0140	0.9069
error	21	25.3286	1.2061		
over-all model p value					0/0008

TableH6: Analysis of deviance tables for Cowlitz references using single river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	8.7391				
flow.a + flow.b	2	1.9368	0.%84	3.2743	0,0561	0.2216
error	23	6.8024	0.2958			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	8.7391				
spill.a + spill.b	?	1.3020	0.6510	2.0133	0.1564	0.1490
error	23	7.43:1	0.3234			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	8.7391				
turb.a + turb.b	,	2.2360	1.1180	3.95-$0	0.0334	0.2559
error	23	6.5032	0.2827			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	8.-39 1				
tempt.a + tempc.b	2	0.8769	0.4384	1.2827	0.2964	0.1003
-	23	7.8622	0.3418			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	8.7391				
spill ratio	1	1.1989	1.1989	3.8159	0.0625	0.1372
error	24	7.5403	0.3142			

source	d.f.	Deviance	Mean Dev	F	p	R^2
$Total_{corr}$	25	8.7391				
hatchery contribution	1	1.1421	1.1421	3.6080	0.0696	0.1307
error	24	7.5970	0.3165			

TableH7: Analysis of deviance tables for Cowlitz references using two river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	8.7391			
turb.a + turb.b	2	2.2360			
flow.a + flow.b	2	0.4503	0.2252	0.7811	0.4707
error	21	6.0529	0.2882		
over-all model p value					0.0894

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	8.7391			
turb.a + turb.b	2	2.2360			
spill.a + spill.b	2	0.1470	0.0735	0.2429	0.7865
error	21	6.3561	().3027		
over-all model p value					0.1365

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	8.7391			
turb.a + turb.b	2	2.2360			
tempt.a + tempt.b	·	0.9217	0.4608	1.:339	0.2009
error	21	5.5815	0.2658		
over-all model p value					0.0433

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	8.-391			
turb.a + turb.b	2	2.2360			
spill ratio	1	0.0167	0.0167	0.0567	0.8139
error	: -	6.4864	0.2948		
over-all model p value					0.0821

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	8.7391			
turb.a + turb.b	2	2.2360			
hatchery contribution	I	0.04 13	0.0413	0,1-$06	0.7113
-	22	6.4619	0.2937		
over-all model p value					0.0790

TableH8: Analysis of deviance tables for **Washougal** references using single river conditions at McNary Darn and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.0583				
flow.a + flow.b	2	6.0512	3.0256	9.9313	0.0008	0.4634
-	23	7.0071	0.3047			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	2.5	13,05s3				
spill.a + spill.b	2	3.5358	1.7679	4.2701	0.0265	0.2708
error	23	9.522S	0.4140			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.0583				
turb.a + turb.b	2	4.0179	2.0090	5.1109	0.0146	0.3077
-	23	9.04435	0.3931			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.0583				
tempt.a + tempt.b	2	3.4008	1.7004	.$.04%	0,0311	0.2604
-	23	9.6575	0.4199			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.0583				
spill ratio	1	2.6805	2.6805	6.1989	0.0201	0.2053
error	24	10.3778	0.4324			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	2s	13.0583				
hatchery contribution	1	0.6759	0.6759	1.3102	0.2637	0,0518
error	24	12.3824	0.5159			

TableH9: Analysis of deviance tables for Washougal references using two river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dew.	F	p
$Total_{corr}$	25	13.0583			
flow.a + flow.b	2	6.0512			
spill.a + spill.b	2	1.4284	0.7142	2.6884	0.0913
-	21	5.5787	0.2657		
over-all model p value					0.0009

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	13.05s3			
flow.a + flow.b	2	6.0512			
turb.a + turb.b	2	0.7150	0.3575	1.1932	0.3230
error	21	6.2921	0.2996		
over-all model p value					0.0030

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	13.0583			
flow.a + flow.b	2	6.0512			
tempt.a + tempt. b	2	0.5820	().Z910	0.9510	0.4024
error	21	6.4251	0.3060		
over-all model p value					0.0037

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	13.0583			
flow.a + flow.b	2	6.0512			
spill ratio	1	1.5571	1.5571	6.2854	0.0201
error	22	5.4500	0.2477		
over-all model p value					0.0002

source	d.f.	Deviance	Meao Dev.	F	p
$Total_{corr}$	25	13.0583			
flow.a + flow.b	2	6.0512			
hatchery contribution	1	0.0142	0.0142	0.0448	0.8344
error	22	6.9928	0.3179		
over-d model p value					0.0029

TableH10: Analysis of deviance tables for Washougal references using three river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	13.0583			
flow.a + flow.b + spill ratio	3	7.6083			
turb.a + turb.b	2	0.0211	0.0106	0.0389	0,%20
error	20	5.4289	0.2714		
over-all model p value					0.(X)21

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	13.0583			
flow.a + flow.b + spill ratio	3	7.6083			
tempt.a + tempt.b	?	0.281I	0.1406	0.5439	0.58S8
error	20	5.1689	0.2584		
over-all model p value					0.0014

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	2s	13.05S3			
flow.a + flow.b + spill ratio	3	7.6083			
hatchery contribution	1	0.0092	0.0092	0.0355	0.852-$
error	21	5.4408	0.2591		
overall model p value					o. 0007

TableH1 1: Analysis of deviance tables for Tanner Creek references using single river conditions at McNary Darn and observed counts, adjusted for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{corr}}$	27	73.4319				
flow.a + flow.b	2	28.7538	14.3769	8.0447	0.0020	0.3916
error	2s	44.6781	1.7871			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{corr}}$	27	73.4319				
spill.a + spill.b	2	32.7892	16.3946	10.0846	0.0006	0.4465
error	25	40.6428	1.6257			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{corr}}$	27	73.4319				
turb.a + turb.b	2	25.6002	12.8001	6.691X!	0.0047	0.3486
-	25	47.8318	1.9133			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{corr}}$	27	-3.4319				
tempt.a + tempt. b	?	1.8252	0.9126	0.31 S6	0.7301	0.0249
error	25	-1.6068	2.8643			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$\text{Total}_{\text{corr}}$	27	-3.4319				
spill ratio	1	30.5813	30.5813	18.5554	0.0002	0.4165
error	26	42.8507	1.6481			

source	d.f.	Deviance	Mean De\.	F	p	R^2
$\text{Total}_{\text{corr}}$	27	73.4319				
hatchery contribution	1	25.0034	25.0034	13.4237	0.0011	0.3405
error	26	48.-$286				

Table H12: Analysis of deviance tables for Tanner Creek references using two river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	73.4319			
spill ratio	1	30.5813			
flow.a + flow.b	2	0.0854	0.0427	0.0240	0.9763
error	24	42.7652	1.7819		
over-all model p value					0.0042

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	73.4319			
spill ratio	1	30.5813			
turb.a + turb.b	2	18.7747	9.3874	9.3578	0.0010
error	24	24.0759	1.0032		
over-all model p value					2.04×10^{-10}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	73.4319			
spill ratio	1	30.5813			
tempt.a + tempt.b	2	10.5583	5.2791	3.9235	0.0336
error	24	32.2924	1.3455		
over-all model p value					0.0002

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	-3.4319			
spill ratio	1	30.5813			
hatchery contribution	1	14.6830	14.6830	13.0318	0.0013
error	25	28.1677	1.1267		
over-all model p value					4.90×10^{-09}

TableH13: Analysis of deviance tables for Tanner Creek references using three river conditions at McNary Darn and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	73.4319			
spill ratio + turb.a + turb.b	3	49.3760			
flow.a + flow.b	2	1.4894	0.7447	0.7254	0.-$954
error	22	22.5 865	1.0267		
over-all model p value					4.57X1045

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	73.4319			
spill ratio + turb.a + turb.b	3	49.3760			
tempt.a + tempt.b	2	8.5878	4.2939	6.0993	0.0078
-	22	15.4881	0.7040		
over-all model p value					$8.58x10^{-07}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	73.4319			
spill ratio + turb.a + turb. b	3	49.3760			
hatchery contribution	1	2.6108	2.6108	2.7975	().1080
error	23	21.4651	0.9333		
over-all model p value					$6.58x10^{-06}$

TableH14: Analysis of deviance tables for Tanner Creek references using all four river conditions at McNary Dam and observed counts, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
Total_{corr}	27	73.4319			
spill ratio + turb.a + turb.b + tempt.a + tempt.b	5	57.9438			
flow.a + flow.b	2	0.7105	0.3552	0.4808	0.6253
error	20	14.’7776	0.7389		
over-all model p value					9.33×10^{-06}

Source	d.f.	Deviance	Mean Dev.	F	p
Total_{corr}	27	73.-$319			
spill ratio + turb. a + turb. b + tempt.a + tempc. b	5	57.9438			
hatchery contri bution	1	0.4988	0.4988	0.6988	0.4126
error	21	14.9893	0.7138		
over-all model p value					2.70×10^{-06}

Appendix I: ANODEV Tables for Model (5)

Table of Tables

Table 11: Analysis of deviance tables for Grays River references, using single river conditions at McNary Dam and vpa counts, unadjusted for the probability for transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.9056				
flow.a + flow.b[a]	2	3.5333	1.7666	1.7239	0.2119	0.1869
error	15	15.3723	1.0'248			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.9056				
spill.a + spill.b	?	3.4967	1.7484	I.7020	0.2157	0.1850
en-or	15	15.4089	1.0273			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.9056				
turb.a + turb.b	2	3.3469	1.673-!	1.613-I	0.2319	0.1770
error	15	15.55X:	1.0372			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{COn}$	17	18.9056				
tempt.a + tempt.b	·	6.--80	3.3890	J.191-	0.0358	0.3585
en-w	15	1:.12:6	0.8085			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.9056				
spill ratio	1	3.1-98	3.1-98	3.2352	0.0910	0.1682
error	16	15.7259	0.9829			

source	d.f	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	18.9056				
hatchery contribution	1	4.1552	4.1552	4.5071	0.0497	0.2198
-	16	14.7505	0.9219			

a. "a" ending indicates the intercept. "b"' indicates the slope of the linear regression for that variable.

Table 12: Analysis of deviance tables for Grays River references using two river conditions at McNary Darn and vpa counts, unadjusted for the probability for transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b	2	6.7780			
spill.a + spill.b	2	1.3313	0.6656	0.8015	0.4696
-	13	10.7963	0.8305		
over-all model p value					0.0993

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b	2	6.7780			
turb.a + turb.b	2	1.1569	0.5784	0.6855	0.5212
error	13	10.9707	0.8439		
over-all model p value					0.1084

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	1S.9056			
tempt.a + tempt.b	?	6.7780			
flow.a + flow.b	2	1.6108	0.8054	0.9955	0.3960
-	13	10.5168	0.8090		
over-all model p value					0,0858

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b	2	6.7780			
spill ratio	1	0.9313	0.9313	1.1645	0.2988
error	14	11.1%3	0.-99:		
over-d model p value					0.0556

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b	2	6.7780			
hatchery contribution	1	3.5%1	3.595 I	5.8987	0.0292
error	14	8.5325	0.6095		
over-all model p value					0.0093

Table 13: Analysis of deviance tables for Grays River references using three river conditions at McNary Dam and vpa counts, unadjusted for the probability for transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b + hatchery contribution	3	10.3731			
spill.a + spill.b	2	1.2900	0.6450	1.0686	0.3740
errs	12	7.2426	0.6036		
over-all model p value					0.0256

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b + hatchery contribution	3	10.3731			
turb.a + turb.b	2	1.0656	0.532s	0.8563	0.449 1
-	12	7.4669	0.6222		
over-all model p value					0.0300

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9056			
temp.a + temp.b + hatchery contribution	3	10.3731			
flow.a + flow.b	2	1.1180	0.5590	0.9047	0.4306
error	12	7.4146	0.6179		
over-all model p value					0.0289

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	18.9Q56			
temp.a + temp.b + hatchery contribution	3	10.3731			
spill ratio	1	0.8887	0.8887	1.5115	0.2407
error	13	7.6438	0.5880		
over-all model p value					0,0135

No further information is gained by adding more river conditions to the regression. The best model for the Gray's River-Priest Rapids comparison is temperature+ hatchery contribution.

Table 14: Analysis of deviance table for Bonneville Brights references using single river conditions at McNary Darn and vpa counts, unadjusted for the probability for transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	63.6718				
flow.a + flow.b	2	12.69911	6.3495	2.98%	0.0693	0.1994
-	24	50.9728	2.1239			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	63.6'718				
spill.a + spill.b	2	15.0882	7.5441	3.7267	0.0390	0.2370
error	24	48.5837	2.0243			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	63.6718				
turb.a + turb.b	2	28.8177	14.408S	9.9217	0.0007	0.4526
error	24	34.8542	1.452.3			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	63.6718				
tempc.a + tempt.b	2	4.5430	2.2715	0.9220	0.4114	0.0714
error	24	59.1288	2.4637			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	63.6718				
spiff ratio	1	10.6766	10.6766	5.0366	0.0339	0.1677
error	25	52.9953	2.1198			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	26	63.6718				
hatchery contribution	1	27.2348	27.2348	18.6862	0.0002	0.4277
error	25	36.-$370	1.4575			

Table 15: Analysis of deviance table for Bonneville Brights references using two river conditions at McNary Darn and vpa counts, unadjusted for the probability for transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	63.6718			
hatchery contribution	1	27.2348			
spill.a + spill.b	2	3.4267!	1.7131	1.1936	0.3212
-	23	33.0108	1.4353		
over-all model p value					0.0015

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	63.6:18			
hatchery contribution	1	27.2348			
tempt.a + tempt.b	2	3.3979	1.6990	1.1827	0.3244
error	23	33.03'?1	1.4365		
over-all model p value					0.0015

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	63.6:1 8			
hatchery contribution	1	27.2348			
flow.a + flow.b	?	2.3438	1.1719	0.7906	0.4655
error	23	34.0932	1.4823		
over-all model p value					0.0021

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	63.6718			
hatchery contribution	1	27.2348			
spiff ratio	1	2.6393	2.6393	1.8742	0.183-
-	24	33.7977	1.4082		
over-all model p value					0.0005

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	63.6718			
hatchery contribution	1	27.2348			
turb.a + turb.b	2	5.0484	2.5242	1 .8-a%	0.1:99
	23	313886	1.3647		
over-all model p value					0.0009

Table 16: Analysis of deviance tables for Cowlitz references using single river conditions at McNary Darn and vpa counts, unadjusted for the probability for transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	12.1810				
flow.a + flow.b	2	0.6181	0.3090	0.6148	0.5494	0.0507
error	23	11.5629	0.5027			

Source	d.f.	Deviance	Mesa Dev.	F	p	R^2
$Total_{corr}$	25	12.1810				
spill.a + spill.b	2	0.9874	0.4937	1.0144	0.3783	0.0811
error	23	11.1936	0.4867			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	12.1810				
turb.a + turb.b	2	0.8927	0.4464	0.9094	0.4168	0.0733
error	23	11.2883	0.4908			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	12.1810				
tempt.a + tempt.b	2	o,~461	0.1231	0.2372	0.-908	0.0202
error	23	11.93-IQ	0.5189			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	12.1810				
spill ratio	1	0.692	0.69?	1.44-2	0.240-	0.0569
error	24	11.4883	0.4:8			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	12.1810				
hatchery contribution	1	0.4446	0.4446	0.9091	0.3499	0.0365
error	24	11.7365	0.4890			

Table 17: Analysis of deviance tables for Washougal references using single river conditions at McNary Dam and vpa counts, unadjusted for the probability for transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
Total_	25	14.8628				
flow.a + flow.b	2	3.3860	1.6930	3.3929	0.0511	0.2278
error	23	11.4768	0.4990			

SOW-LX	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	14.8628				
spill.a + spill.b	2	2.0621	1.0311	1.8526	0.1-95	0.1387
error	23	12.8007	0.5566			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	1-$.862s				
turb.a + turb.b	2	2.3503	1.1752	2.1601	0.1381	0.1581
error	23	12.5125	0.5440			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	14.862s				
tempt.a + tempc.b	2	4.0687	2.0344	4.3348	0.0253	0.2`38
errs	23	10.-94 I	0.4693			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	14.8628				
spill ratio	1	1.9217	1.9217	3.5639	0.0- I 2	(),1293
error	24	12.9411	0.5392			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	14.8628				
hatchery contribution	1	0.3528	0.3528	0.5836	0.4523	0.0237
errs	24	1-$.5100	0.6046			

Table 18: Analysis of deviance tables for Washougal references using two river conditions at McNary Darn and vpa counts, unadjusted for the probability for transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	14.8628			
tempt.a + tempt.b	2	4.0687			
flow.a + flow.b	2	1.0566	0.5283	1.1393	0.3390
error	21	9.7375	0.4637		
over-all model p value					0.0545

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	14.8628			
tempt.a + tempt.b	2	4.0687			
turb.a + turb.b	2	0.8450	0.4225	0.S918	0.4249
-	21	9.9491	0.4738		
over-all model p value					0.0661

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	14.8628			
tempt.a + tempt.b	2	4.0687			
spill.a + spill.b	2	1.0042	0.5021	1.07-	0.3587
error	21	9.%99	().4662		
over-d model p value					0.05-2

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	23	14.s628			
tempt.a + tempc.b	2	4.0687			
spill ratio	I	0.4464	0.4464	0.9491	0.3405
error	22	10.3477	0.4704		
over-all model p value					0.0432

soul-.x	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	2s	14.8628			
tempt.a + tempt.b	2	4.0687			
hatchery contribution	1	0.0005	0.0005	0.C4)1O	0.9750
-	22	10.7936	0..$906		
over-d model p value					0.0661

Table 19: Analysis of deviance tables for Tanner Creek references using single river conditions at McNary Dam and vpa counts, unadjusted for the probability for transportation.

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	67.7441				
flow.a + flow.b	2	23.2444	11.622'2	6.5294	0.0052	0.3431
error	25	44.4997	1.7800			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	67.7441				
spill.a + spill.b	2	28.9709	14.-4s54	9.3398	0.0009	0.4277
-	25	38.7732	1.5509			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	67.7441				
turb.a + turb.b	2	24.7600	12.3800	7.2004	0.0034	0.3655
error	25	42.9841	1.7194			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	6:.?.!41				
tempt.a + tempt b	2	1.0636	0.5318	0.1994	0.8205	0.0157
error	2s	66.6S05	2.6672			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	67.7441				
spill ratio	1	26.0935	26.0935	16.2886	0.0004	0.3852
error	26	41.6506	1.6019			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
Total_	27	67.7441				
hatchery contribution	1	27.2072	27.2072	17.4505	0.0003	0.4016
error	26	40.5369	1.5591			

Table 110: Analysis of deviance tables for Tanner Creek references using two river conditions at McNary Dam and vpa counts, unadjusted for the probability for transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	6?.7441			
hatchery contribution	1	27.2072			
flow.a + flow.b	2	14.1704	7.0852	6.4493	0.0057
-	24	26.3665	1.0986		
over-all model p value					$3.90x10^{-05}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution	1	27.2072			
turb.a + turb.b	2	1 1.4826	5.7413	4.7426	0.0184
error	24	?9.0542	1.2106		
over-all model p value					0.0001

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution	1	27.2072			
temp.a + temp.b	2	2.3508	1.1754	(),738s	0.48S3
error	24	38.1860	1.5911		
over-all model p value					0.0029

Sours	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution	1	27.2072			
spill.a + spill.b	2	16.8241	8.4120	8.5139	0.0016
-	24	23.7128	0.9880		
over-all model p value					$1.12x10^{-05}$

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution	1	27.2072			
spill ratio	1	16.1347 -	16.1347	16.5300	0.0004
-	25	24.4021	0.9761		
over-all model p value					$2.86x10^{-06}$

Table 111: Analysis of deviance tables for Tanner Creek references using three river conditions at McNary Darn and vpa counts, unadjusted for the probability for transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution + spill ratio	2	43.3419			
flow.a + flow.b	2	0.8855	0.4-$28	0.4330	0.6537
error	23	13.516:	1.0225		
over-all model p value					$4.42x10^{-05}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution + spill ratio	2	43.3-$19			
turb.a + turb.b	2	6.3700	3.1850	4.0625	0.0308
error	23	18.0321	0.7840		
over-all model p value					$2.31x10^{-06}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution + spill ratio	2	43.3419			
temp.a + temp.b	2	2.5376	1.2688	1.33'4-	().2s29
error	23	21.8645	0.95(36		
over-all model p value					$1.98x10^{-05}$

Table 112: Analysis of deviance tables for Tanner Creek references using four river conditions at McNary Dam and vpa counts, unadjusted for the probability for transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution + spill ratio + turb.a + turb.b	4	49,7119			
flow.a + flow.b	2	0.2138	0.1069	0.1260	0,8823
error	21	17.8183	0.8485		
over-all model p value					3.38×10^{-05}

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	67.7441			
hatchery contribution + spill ratio + turb.a + turb. b	4	49.7119			
tempt.a + tempt.b	2	4.2532	2.1266	3.2411	0.0593
error	21	13.7789	0.6561		
over-all model p value					2.61x1O*

Appendix J: ANODEV Tables for Model (6)

Table J1: Analysis of deviance tables for Grays River references, using single river conditions at McNary Darn and adjusting for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4203				
flow.a + flow.b[a]	2	4.9790	2.4895	2.4183	0.1229	0.2438
error	15	15.4414	1.0294			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4203				
spill.a + spill.b	2	5.0154	2.5077	2.4418	0.1208	0.2456
error	15	15.4049	1 . 0 2 7 0			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4203				
turb.a + turb.b	2	4.2698	2.1349	1.9828	0.1722	0.2091
error	15	16.1505	1.0767			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4203				
tempt.a + tempt.b	2	7.5338	3.7669	4.3847	0.0317	0.3689
-	15	12.8865	0.8591			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	I7	20.4'203				
spill ratio	I	4.7010	4.7010	4.7849	0.0439	0.2302
error	16	15.7194	0.9825			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	17	20.4203				
hatchery contribution	1	4.2314	4.231-$	4.1820	0.0577	0.2072
error	16	16.1890	1.0118			

a. "a" ending indicates the intercept, ".b" indicates the slope of the linear regression for that variable.

Table J2: Analysis of deviance tables for Grays River references using two river conditions at McNary Dam and adjusting for probability of transportation.

Source	d.f.	Deviance	Mean Dev	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b	2	7..5338			
spill.a + spill.b	2	2.0906	1.0453	1.2587	0.3164
error	13	10.7959	0.8305		
over-all model p value					0.0645

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b	2	7.5338			
turb.a + turb.b	'	1.6026	0.8013	0.9232	0..$218
error	13	11.2839	0.8680		
over-all model p value					0.0827

Source	d.f'.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
tempt.a + tempt.b	'	'.5338			
flow.a + flow.b	·	2.4257	1.2128	1.5072	0.2578
error	13	10.4608	0.8047		
over-all model p value					().0539

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b	2	7.5338			
spill ratio	1	1.6668	1.6668	2.0798	0.1713
-	14	11.2198	0.8014		
over-all model p value					0.0342

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	1-	20.4203			
temp.a + temp.b	2	7.5338			
hatchery contribution	1	3.6053	3.6053	5..$383	0.03s 1
-	14	9.2812	0.6629		
over-all model p value					0.(X)98

Table J3: Analysis of deviance tables for Grays River references using three river conditions at McNary Dam and adjusting for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b + hatchery contribution	3	11.1391			
spill.a + spill.b	2	2.0399	1.0200	1.6902	0.2256
-	12	7.2413	0.6034		
over-all model p value					0.0170

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b + hatchery contribution	3	11.1391			
turb.a + turb.b	?	1.3648	0.6824	1.0344	0.3851
error	12	7.9164	0.65.97		
over-all model p value					0.0272

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b + hatchery contribution	3	11.1391			
flow.a + flow.b	·	1.8015	0.9008	I .4451	0.2740
-	12	-.J-9-	0,6233		
over-all model p value					0.0202

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	17	20.4203			
temp.a + temp.b + hatchery contribution	3	11,1391			
spiff ratio	1	1.6096	1.6096	' _.7277	0.1226
-	13	7.6716	0.590 I		
over-all model p value					0.0087

Table J4: Analysis of deviance table for Bonneville Brights references using single river conditions at McNary Dam, adjusted for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
Total_{corr}	26	66.9975				
flow.a + flow.b	2	15.8562	7.9281	3.7206	0.0391	0.0555
-	24	51.1413	2.1309			

source	d.f.	Deviance	Mean Oev.	F	p	R^2
Total_{corr}	26	66.9975				
spill.a + spill.b	2	1 8.6%6	9.3483	4.6450	0.0197	0.2791
en-of	24	48.3009	2.0125			

source	d.f.	Deviance	Mean Dev.	F	p	R
Total_{corr}	26	66.9975				
turb.a + turb.b	2	31.3672	15.6836	10.5642	0.(X)05	0.4682
-	24	35.6303	1.4846			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
Total_{corr}	26	66.9975				
tempc.a + tempt.b	[illegible]	3.%7-	1.9838	0.7554	0.-$80-	0.0592
error	24	63.0298	2.6262			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
Total_{corr}	26	66.9975				
spill ratio	1	0.35-$0	0.3540	0.1328	0 .186	0.(X353
-	2.5	66.6135	2.6657			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
Total_{corr}	26	66.9%5				
hatchery contribution	1	28.9757	28.9757	19.0520	0.0002	0.432.5
-	2s	38.0218	1.5209			

Table J5: Analysis of deviance table for Bonneville Brights references using two river conditions at McNary Darn, adjusting for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	66.9975			
hatchery. contributi on	1	28.9757			
spill.a + spill.b	2	5.1345	2.5672	1.7954	0.1886
error	23	32.8873	1.4299		
over-all model p value					0.0008

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	66.9975			
hatchery. contribution	1	28.9757			
tempt.a + tempt.b	2	3.6208	1.8104	1.2104	0.3164
error	23	34.4010	1.4957		
over-all model p value					0.0013

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	66.9975			
hatchery.contribute on	1	28.9757			
flow.a + flow.b	2	3.6722	1.8361	1.2294	0.3110
-	23	34.3-t%	1.-$935		
over-all model p value					0.0013

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	66.9975			
hatchery.contributi on	1	28.9757			
spill ratio	1	4.1435	4.1-$35	2.9353	().()096
error	24	33.8783	1.4116		
over-all model p value					0.(X)03

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	26	66.9975			
hatchery.contribute on	1	28.975:			
turb.a + turb.b	2	5.9569	2.9784	2.1364	0.1409
error	23	32.0649	1.3941		
over-all model p value					0.0006

Table J6: Analysis of deviance tables for Cowlitz references using single river conditions at McNary Dam and adjusting for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.1577				
flow.a + flow.b	2	1.4224	0.7112	1.3939	0.2683	0.1081
error	23	11.7353	0.5102			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.1577				
spill.a + spill.b	2	2.0288	1.0144	2.0964	0.1458	0.1542
error	23	11.1289	0.4839			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.1577				
turb.a + turb.b	2	1.4615	0.7308	1.4370	0.2582	0.1111
error	23	11.6962	0.5085			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.157-				
tempc.a + tempt. b	2	0.3674	0.183-	0,3303	0.722 1	0.0279
-	23	12.:903	0.5561			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.1577				
spill ratio	1	1.5999	1.5999	3.3223	0.0808	0.1216
error	24	11.557-	0.4816			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	13.157:				
hatchery contribution	1	0.6542	0.6542	1.2557	0.2736	0.049-
-	24	12.5035	0.5210			

Table J7: Analysis of deviance tables for Washougal references using single river conditions at McNary Dam and adjusting for probability of transportation.

Source	d.f.	Deviance	Meao Dev.	F	p	R^2
$Total_{corr}$	25	16.2471				
flow.a + flow.b	2	4.9583	2.4792	5.0511	0.0152	0.3052
error	?3	11.2887	0.4908			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	16.2471				
spill.a + spill.b	2	3.4424	1.7212	3.0916	0.0647	0.2119
error	23	12.8047	0.5567			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	16.2.$71				
turb.a + turb.b	2	3.2215	1.6107	2.8442	0.0787	0.1983
error	23	13.0255	0.5663			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	16.2471				
tempt.a + tempt.b	2	4.6435	2.3218	4.6021	0.0208	0.2858
error	23	11.6435	0.5045			

Source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	16.2471				
spill ratio	1	33082	3.3082	6.1363	0.0207	0.2036
error	24	12.9389	0.5391			

soul-lx	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	25	16.2471				
hatchery contribution	1	0.2550	0.2550	0.3 827	0..5420	0.0157
-	24	15.9920	0.6663			

Table J8: Analysis of deviance tables for Washougal references using two river conditions at McNary Darn and adjusting for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	16.2471			
flow.a + flow.b	2	4.9583			
spill.a + spill.b	2	0.2110	0.1055	0.2000	o. 8203
-	21	11.0778	0.5275		
over-all model p value					0.0778

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	2s	16.2471			
flow.a + flow.b	2	4.9583			
turb.a + turb.b	2	0.2724	0.1362	0.2596	0.7738
error	21	11.0163	0.5246		
over-all model p value					0,0741

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	2s	16.2.$:1			
flow.a + flow.b	2	4.9583			
tempc.a + tempc.b	2	1.5605	0.7802	1.6843	0.2097
error	21	9.7282	0.4632		
over-d model p value					0.0239

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	16.2471			
flow.a + flow.b	2	5.9583			
spill ratio	1	0.1683	0.1683	0.3330	0.5697
error	22	11.1204	0.5055		
over-all model p value					0.0364

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	25	16.2471			
flow.a + flow.b	2	4.9583			
' hatchery contribution	1	1.3901	1.3901	3.0894	0.092-
-	22	9.8987	0.4499		
over-all model p value					0.0110

Table J9: Analysis of deviance tables for Tanner Creek references using single river conditions at McNary Dam and adjusting for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	72.5599				
flow.a + flow.b	2	27.4731	13.7366	7.6167	0.0026	0.3786
-	25	45.0868	1.8035			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	72.5599				
spill.a + spill.b	2	34.0078	17.0039	11.0266	0.0004	0.4687
error	25	38.5521	1.5421			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	72.5599				
turb.a + turb.b	2	26.788:	13.3944	:.3159	0.0032	0.3692
error	2s	45.7712	1.8308			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	72.5599				
tempt.a + tempt.b	2	0.933	0.4662	0.1627	0.8507	0.01285
error	25	71.6276	2.8651			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	72.5599				
spill ratio	1	30.8605	30.8605	19..?.518	0.0002	0.4253
-	26	41.6994	1.6038			

source	d.f.	Deviance	Mean Dev.	F	p	R^2
$Total_{corr}$	27	72.5599				
hatchery contribution	1	28.4976	28.4976	16.815-	0.0004	0.3927
error	26	4.\$.0623	1.6947			

Table J1O: Analysis of deviance tables for Tanner Creek references using two river conditions at McNary Dam and adjusting for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio	1	30.8605			
flow.a + flow.b	2	0.0388	0.0194	0.0112	0.9889
error	24	41.6607	1.7359		
over-all model p value					0.0035

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio	1	30.8605			
turb.a + turb.b	2	19.9555	9.9778	11.0129	0.0004
error	24	21.7440	0.9360		
over-all model p value					1.80×10^{-06}

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio	1	30.8605			
tempt.a + tempt.b	2	13.8954	6.9477	5.9971	0.0077
error	24	27.8041	1.1585		
over-all model p value					3.25×10^{-05}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio	1	30.8605			
hatchery contribution	1	17..$153	17.-$153	17.9287	0.0003
-	25	24.2841	0.9714		
over-all model p value					1.14×10^{-06}

Table J11: Analysis of deviance tables for Tanner Creek references using three river conditions at McNary Dam and adjusted for probability of transportation.

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio+ hatchery contribution	2	48.2758			
flow.a + flow.b	2	0.8431	0.4216	0.4136	0.6661
error	23	23.4411	1.0192		
over-all model p value					2.00×10^{-05}

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio + hatchery contribution	2	48.2758			
turb.a + turb.b	2	6.3226	3.1613	4.0481	0.0312
error	23	17.9615	0.7809		
over-all model p value					1.03×10^{-06}

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio + hatchery contribution	2	48.2758			
tempt.a + tempt.b	2	2.6460	1.3230	1.4063	0.2653
error	23	21.638	0.9408		
over-all model p value					8.22×10^{-06}

Table J12: Analysis of deviance tables for Tanner Creek references using four river conditions at McNary Dam and adjusting for probability of transportation.

source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio + hatchery contribution + turb.a + turb.b	4	54.5984			
flow.a + flow.b	2	0.2563	0.1281	0.1520	0.8599
-	21	17.7052	0,8431		
over-all model p value					$1.61x10^{45}$

Source	d.f.	Deviance	Mean Dev.	F	p
$Total_{corr}$	27	72.5599			
spill ratio + hatchery contribution + turb.a + turb.b	4	54.5984			
tempc.a + tempc.b	2	4.261	2.1308	3.2663	0.0582
-	21	13.6999	0.6524		
over-all model p value					$1.23x10^{-06}$

Appendix K1: Peer Reviewers' comments

Manuscript Review

1. **Identification:** Skalski, J. R., R.L. Townsend, R. F. Donnelly, and R. W. Hilborn (April 1996) The relationship between survival of Columbia River fall chinook salmon and inriver environmental factors. Final Report, Analysis of Historic Data for Juvenile and Adult Salmonid Production: Phase II. Center for Quantitative Science, School of Fisheries, University of Washington, Seattle, WA 98195. Prepared for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208-3621. Project Number 87413-02, Contract Number DE-BI79-87BO35885, Task Order AT79-89-BP01772.

2. **How this review is constructed. The** review consists of four parts; specific comments on the scientific content of the manuscript, editorial comments, comparison to past review, and comments written directly on the original copy of the manuscript which is enclosed. The specific comments are summarized and a few are elaborated in the letter of transmittal. Please note that the edited copy of the manuscript is an important part of the review. For example, problems encountered in understanding the mathematical notations and definitions of statistics and parameters are noted directly on the manuscript along with suggestions for clarification. The order of the specific and editorial comments follows that of the manuscript.

3. **Recommendation. I** recommend this manuscript be accepted for publication with revisions which are discussed as stated in paragraph 2.

Specific Comments

Note that these comments may be in addition to those written on the enclosed copy of the manuscript and the letter of transmittal.

Introduction

1.1 The relevant background is that the Columbia River basin has been profoundly altered with respect to the physical attributes (temperature, flow, geomorphology, and many more) which characterize the normative salmon bearing ecosystem. Given the observations and analyses in the manuscript most of this section seems gratuitous. Recommend that most of sections 1.1 and 1.2 be deleted. Retain information relevant to the factors evaluated. For example, the first full paragraph on page 2 looks like a keeper. Last paragraph before section 1.2 looks like a hold over from Hilborn et al.

1.2 **This** section illustrates why I counsel keeping the introductory verbiage to a minimum. The rationale for inclusion of turbidity-which is given here is very weak, and it is not supported by citations to the primary literature. Not that turbidity should have been excluded, but what, exactly, is the mechanism of mortality associated with turbidity? Why do juvenile salmon avoid turbidity? What does juvenile emigrant mortality have to do with turbidity? Junge and Oakley (1966) hypothesized that reductions in turbidity in McNary forebay would-increase mortality of juvenile salmon emigrants, and that decreases in turbidity would increase the length of time needed for emigration because juvenile salmon would hesitate to move during daylight hours in low turbidity conditions. In the reference section I have included some general and specific references on mechanisms of salmon migration. In section 3.3.5 the best rationale for studying flow, temperature and turbidity is given on page 46, top of the page.

Page 5, para. 1 To what extent are any of the other "independent" variables actually independent of flow? How can the confounding effects of covariates of flow be removed? To what extent is natural mortality in the marine environment related to broad scale climatic factors which also determine runoff and other water movement variables? Take care not to trivialize the development of the flow-survival hypothesis. The version of the hypothesis current in the CR basin, although extremely simplistic, is consistent with a much larger literature on the role of water movements in the life cycles of anadromous and catadromous fishes. Hynes (1970) has a good introduction to the older more descriptive literature on the ecology of lotic waters, which the synthesis of flow survival which Glenn Cada did for the Northwest Power Planning Council did not include. Note that the NPPC Fish and Wildlife Program has evaluation of the flow-survival hypothesis as an explicit objective. Citing this would help establish the relevancy of this work to CR salmon recovery.

Page 5, para 2. The effects of temperature are likely to be cumulative, as weii as acute. Timing of emergence, starvation, and basic physiological mechanisms such as enzyme systems, ail function with respect to temperature based on cumulative effects and thresholds. For exampie see Holtby et al. 1988 and references cited, and Northcote 1984. April through August might not be the appropriate time frame for temperature with respect to faii chinook juveniles. There may be no "right" time period. See the cover letter to this review, and commentary later on. Literature cites are lacking.

Page 5, para 3. Lack of literature citations and incautious selection of words makes this paragraph most unfortunate. Scientists "believe" that spill is the lowest mortality route of hydroelectric project passage because tagging experiments involving hundreds of thousands of marked members have demonstrated it to be so. There are no estimates of mortality owing to gas bubble disease based on tagged members, or any other method, because the extent to which the nitrogen supersaturated water coincides with the path of the emigrants has not been measured. So the equation of the level of scientific knowledge on these two sources of mortality, spill and GBD, as "beliefs" is cavalier and inappropriate.

Page 5, para. 3. "Increased spill is thought to result in increased flow, . . . " By whom? This is physically impossible, since the route that water takes through a hydroelectric project has no bearing on the volume of water per unit time coming down the river, although the time rate of change in volume of water can force the project operator to spill. Fact: Juvenile salmon downstream movement, including emigration, is deiayed by hydroelectric projects, especially during times of the day when generation of electricity is sharply reduced, or stopped, if water is not sent over the spill ways. Fact: Spill alters prey fields of predators below dams in ways favorable to juvenile emigrants.. Hypothesis supported by empiricism: Provision of spill reduces delay in hydroelectric project passage, and it provides the highest known project passage survival. Alternative hypotheses, unsupported by *in situ* empirical evidence, which question the value of spill based on negative effects of Gas Bubble Disease, have been advanced, and should not be discounted. However, the GBD hypotheses are based on *in vitro* observations which may, or may not, translate into *in situ* mortalities. *In situ* observations of acute effects of GBD in fish handling facilities at dams do not translate into mortality estimates. *in vitro* observations of LD-50 in GBD should not be given the same weight as *in situ* estimates of mortalities of juveniles which have passed over spill ways. Such *in situ* records integrate the mortalities generated by GBD, as weii as other factors. This is most definitely not a trivial point, since credibility depends on impartiality, and it is not scientifically impartial to give equal weight to unequall y substantiated hypotheses. Again, if the literature grounding is not available to you, my advice is to skip it, rather than to risk the appearance of bias. it is reasonable to look at spill in the context of this study because spill is an important operational attribute of the hydroelectric system which may bear on juvenile emigrant survivals, period.

2. Materials and Methods

Page 6- i was surprised not to see any reference hereto the earlier Phase i work by R. Hilborn, M. Pascual, R. Donnelly, C. Coronado-i-iemandez and others cited at this point. is this not based to some extent on those works?

Page 7, Environmentai covariates. Environmental covariates require definition well beyond what is presented here in order to add credibility to the work. Are the conditions really ambient with respect to the emigrants? This central question is not addressed. Since so much hinges on the credibility of these physical variables, the lack of effort in this regard is a serious shortcoming. Specific suggestions on each variable are given below. I recommend adding a table of weekiy averages (April - August) and standard deviations by year with graphs of average over all years with 95% CI for each physical variable. in generai this work is lacking in data summaries and graphs to support the Results section. Suggest using the formats in Appendix A, pp. 26-35.

Flow. For exampie, where exactiy, is flow measured at McNary? is it actually measured, or is it estimated? Does it contain sampling or measurement error, or both? If so, how much? Where do the Hanford Reach emigrants start to experience this flow? For how long do they experience it? What proportion of the emigrants experience which flows? Are flows a surrogate for velocity? Do you postulate a relation among flows, water velocity and fish velocity? The following comment from an earlier review needs to be addressed in the discussion on this point;

> ***Therefore, by picking a fixed time duration*** over ***which*** to ***measure the independent*** variable, informs ***tion from*** outside the time horizon ***of the event may be inappropriately applied to*** explain the ***event.*** As a theoretical example,suppose

that ninety percent of the migration is swept out of the hydroelectric system by high flows during the first week of May. Why then should the flows during the rest of May be a determinant of survival, if mortality factors associated with the hydroelectric system are responsible for the observed survivals?

The problem of obtaining measures of flows as they occurred during the juvenile migration of each tag group, F(g) (Eqn. 2), is part of the general *problem of synchrony* to which studies of this nature are subject. It is important to employ measures of the physical environment that are synchronous with the migration of the population of juveniles to which the survival estimates apply.

Where isternperature at McNary measured? Is this a scroll case temperature or a water surface temperature? How does this temperature compare to the temperatures in the river approaching the project, and to the temperatures in the river below the project? What is the spatial variability in temperature in relation to the spatial variability in distribution offish? Is anything at all known about the spatial distribution of temperature and its potential impact on emigration rates in juveniles?

Where is the turbidity measured? How is it measured? Over what spatial reference frame does itapply?Is this reiated toturbidities upriver or to the effect of impoundment on rates ofsedimentation? (C. Paulsen questioned negative correlation with flow in Table 7, page 25: Junge and Oakley (1966) indicated that McNary pool had effect of reducing turbidities; itisa settling pond.).

The addition of transportation variable is an excellent idea, butnotethe following. The method of construction of the pa_i integrates all of the other physical factors, since these determine the mean and variance of the time distributionof juvenile salmon abundance at McNary. Hence the transportation variable is necessarily correlated with the other physical variables, totheextentthey express physical conditions which are ambient with respect to the emigrants.

Page 13- Selection of stocks for comparison. One wild or semidomesticated animal population is unlikely to ever rigorously satisfy the criteria to serve as a control for another such animal population. Nonetheless, the comparisons are valid so long as the appropriate caveats about the imitations of the data are given. I suggest that pooling all the downriver stocks might provide a surrogate estimator of suitable geographic resolution for lower-river-estuary-early marine effects.

Selection of stocks for comparison. Comments from C. Paulsen.

The first comment is that I do not believe there is enough documentation on how the reference stocks (Bonneville, Cowlitz, etc.) were chosen from the pool of potential reference stocks. A detailed description of the data, including brood years of CWT data used and recovery fractions in each fishery for each potential reference stock, should be included. In addition, more details on selection of tag groups for the reference stocks should be included. The selection of reference stocks was a sore point with reviewers of the earlier draft, and more information is needed to assess the authors' choice of reference stocks.

Second, with an eye toward assessing potential methods for future experiments, it might be instructive to compare different Priest Rapids CWT groups released the same year, to see if they have similar ocean recovery patterns. For example, in 1987 nine tag codes were released (from Table C8, p. 63 of the report). If these nine groups do not have the same ocean recovery patterns, it may suggest that designing tagging, rearing, and release experiments to isolate the effects of in-river migration conditions may be extremely difficult. If one wants to control for ocean conditions by having tag groups with different in-river migration experiences be exposed to the same ocean conditions (the premise of the experiments discussed in Section 4), it would be helpful to assess the similarity of ocean conditions for past releases. A similar comparison could be done for McNary transport and control recoveries, to see if transport affects ocean recovery patterns, Again, if it does make a difference, this does not bode well for the design of future experiments (C. Paulsen 6/14/96).

pp.14-15, Eq. 1 seems to be missing a line or two (C. Paulsen 6/14/96).

p. 15. Need details on the chi-square homogeneity test (C. Paulsen 6/14/96)

p. 22 Table 4- The Euclidean2 column doesn't really add anything to the comparison (C. Paulsen 6/14/96)

Page 25, text and Table 7. The observation that increased flow leads to increased spill is not particularly informative. Note that spill is positively correlated with flow at a dam project only at times when flow exceeds the hydraulic capacity of its powerhouse, except in unusual circumstances such as the Endangered Species Act biological opinion. At flows below hydraulic capacity, the operator may choose whether or not to spill. The table header needs to indicate the time period over which these observations were correlated, and the table should show whether or not each statistic is significantly different from zero.

Page 25, Table 7- Why is it that flow and turbidity are negatively correlated? (CP) is this a function of where turbidity is measured, e.g. Junge and Oakley (1 966)? (PM)

Page 25, last sentence. Also consider that, due to the way in which flow is measured, temperature may happen to be a more appropriate measure of water movement which is ambient with respect to the emigrating juveniles, than is flow.

Section 3.3.5- There is a logical problem created by the fact that this manuscript is a re-analysis of a paper that was never published. To avoid having to include Appendix A in the final report, i suggest this section be moved to the beginning of the methods and results.

Discussion - There is not a one-to-one mapping of the points covered in the paper to the points presented in the Discussion. Perhaps some of the discussion which occurs at the end of presenting the results of each model (1-6, i.e. page 46) could be moved to the discussion. Shorten the CWT narrative by referencing Phase I documents, and by moving the descriptive parts to the Introduction. Next move on to discuss the similarities and inconsistencies of the results of this research to the work of Junge and Oakley, Raymond, Berggren and Filardo, Cada, and others.

Editorial Comments

Additional editorial suggestions are written directly on the enclosed copy of the manuscript.

The use of the construct, “inriver,” which is not found in English, should be replaced by the word, ambient. For example, the title of the paper would read, “The relationship between survival of Columbia River fail chinook salmon and ambient environmental factors”. The use of ambient would distinguish the factors treated in the paper from larger scale environmental factors such as climatic factors. Suggest doing a global search in the manuscript for “inriver” to be replaced by ‘ambient”.

Introduction - crunch 1. 1 and 1.2 down to two paragraphs; paragraph one briefly describing the scientific context by citing Northcote and Howard Raymond’s 1988 NAJFM paper, and the fish and Wildlife Program of the NW Power Council, and paragraph two, describing the history of the Hilborn analysis of hatchery survival data in the Columbia River basin (see first para. Discussion) , and the first effort to match these survivals to physical factors.

Methods - Get the original VPA approach (Appendix A) unadjusted for transportation up front in a box or other separator. Build additional models on to the back of this. This should be model 1. There needs to be a section called, “Appropriate physical measures,” where at least as much attention as has been paid to statistical model selection is paid to the selection and use of the independent variables.

Results - Get the results obtained by applying the original VPA approach (Appendix A) unadjusted for transportation (Section 3.3.5) up front in a box or other separator. Summary data tables and graphics are needed. No need to reproduce the Tables in the Appendix, but summarize behaviors of the physical variables, survivals, and hatchery stats. See specific suggestions above.

Key concerns from a past review

The Scientific Review Group identified a number of concerns in a review made public early in 1994.1 have examined the manuscript with respect to how well it addresses these key concerns. The following is a synopsis of the extent to which these concerns have been addressed.

OUTLINE OF KEY CONCERNS

1. Specify the geographic range to which the results may apply.

There is yet some improvement to be made in this area. The work applies to flows at McNary, and this should be made clear in results and conclusions. It may help to show correlations among Priest Rapids, Ice Harbor and McNary flows.

2. Provide a more rigorous biological description of the populations of salmon included in the study, and to which the conclusions may apply.

Progress has been made, but there is room for improvement. For example, see comments from Paulsen, above.

3. Address key historical and other references, including alternative explanations for the data.

Not much progress here. The addition of temperature, turbidity, and transportation made this task much more onerous, but no less essential. At this late date, it is not recommended to delay the production of the basic results while this is added. Alternative approach is suggested above.

4. Carefully examine and document the reason for selecting the downriver control populations that are used to correct for trends in ex-hydroelectric survival.

Much progress has been made here, although it is clear that one salmon population will never be able to serve as a "control" for another, in the classic experimental sense. The comparisons are valid so long as the appropriate caveats about the limitations of the data are given. The present analysis takes great pains to understand these limitations.

5. Carefully evaluate the selection of the independent variable representing flow with respect to its physical and temporal properties.

Progress has apparently made here, however the extent of this progress is only apparent by careful scrutiny of the data Appendices. Need to acknowledge that the measures of physical factors available at the dams may not be appropriate surrogates for ambient physical conditions for the smelts.

6. Focus the paper on flow survival, lending less effort to discussion of Bayesian statistical methods and general history of the Columbia Basin.

Two steps forward, and one step back. It is not clear what the addition of turbidity and temperature, which are tightly correlated with flow, really added to the understanding of the flow survival relationship. The original hypothesis of Hilborn et al. has been moved into the background, when it should have been the starting point for the analysis. In retrospect, the Bayesian approach doesn't look so bad.

7. Correct misstatements

Much progress here. Basic understanding of the hydroelectric system is much improved.

Some Key References

Berggren, T.J. and M.J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River basin. North American Journal of Fisheries Management 13:48-63.

See the literature cited in; Holtby, L- B., T.E. McMahon, and J. C. Scrivener. 1989. Stream temperature and inter-annual variability in the emigration timing of coho salmon (Oncorhynchus kisutch) smelts and fry and chum salmon (O. keta) fry from Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46:1396-1405.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press.

Junge, C.O. and A. L. Oakley. 1966. Trends in production rates for upper Columbia River runs of salmon and steelhead and possible effects of changes in turbidity. Research Briefs 12(1):22-43. Fish Commission of Oregon, Portland.

T.G. Northcote. 1984. Mechanisms of fish migration in rivers. *Pp. 31* 7-355 *In* J.D. McCleave, G-P. Arnold, J.J. Dodson, and W.H. Neill. eds., 1984. Mechanisms of Migration in Fishes. NATO Conference Series, Plenum Press, New York.

Thorpe, J.E. 1982. Migrations in salmonids with special reference to juvenile movements in freshwater. *Pp.* 86-97 *In* Brannon, E.O. and E.O. Sale, eds. 1992. Salmon and Trout Migratory Behavior Symposium. School of Fisheries, University of Washington, Seattle.

Acknowledgments

Thanks to the Fish Passage Advisory Committee members and their Chair, Dr. Margaret Filardo, for the opportunity for discussions. Thanks to Dr. Charles Paulsen, Paulsen Environmental, and Mr. Bob Heinith, Columbia River Inter-Tribal Fish Commission, for submitting written materials.

Appendix K2: Responses to Peer Reviewers' Specific Comments

Responses to the peer review by Dr. Phillip Mundy have been numbered to correspond to his numbered comments.

Specific Comments

Introduction

1.1: This manuscript has been written for a vast array of potential readers, not all of which maybe familiar with the Columbia River history as Dr. Mundy.

1.2: The mechanisms associated with any environmental factor are uncertain, no more so for turbidity than the other factors examined in this report.

page 5, **para. 1:** Annual plots of the ail the environmental variables investigated in this report were added for a visual comparison. Though a statistical correlation exists between flow and the other covariates, and with each other, there is considerable within-covariate variation, as shown in Figures 1-4. By using a step-wise procedure to build up the model one covariate at a time, any confounding effects of flow would be indicated by the process. Further study involving interaction terms between flow, temperature, etc. would be needed. Interaction terms were not included here, due to the sheer number of models which were explored--with six explanatory variables, there are 720 combinations, and with five reference hatcheries, the analysis increases to 3600 models. Additionally, there were six different approaches (with and without adjustment for the probability of transportation), for a total of 21,600 models to analyze using just the main effects. The goal of this study was to choose lower river stocks to control for the marine effects, so that any natural mortality which may be related to the same broad scale climatic factors also affecting the covariates investigated in this report should not matter, equally affecting both up- and down-river stock.

page 5, **para. 2: This** paragraph has been modified to include more citations and responses to the suggested literature and other sources in regards to temperature and its effects. The temperature was not based on a fixed calendar date, but on the 28-day period following the release of the juveniles into the river, to better characterize conditions actually experienced by the juveniles.

page 5, **para.** 3: Citations have been added, and the paragraph modified to reflect literature findings.

page 5, **para. 3:** Additional concerns of different hypotheses have been addressed.

2. Materials and Methods

page 6: Reference to earlier Phase I work has been cited in sections describing the Virtual Population Analysis and the GLIM analysis methods.

page 7: Additional characterizations of the environmental covariates have been added to the report (Figures 1-4, 6 and Table 1). Figures 1-4 are average weekly measurements of flow, spill, turbidity, temperature. Table 1 contains monthly average and standard errors of the environmental covariates. Fig. 6 is a graph of the annual total biomass contributed by hatcheries to the Columbia River, as calculated by Claribel Coronado- Hemandez (personal communication). In regards to more details about the river data used in this analysis, the source is referenced on pg. 7, para. 3 (United States Army Corps of Engineers (USCOE) Annual Fish Passage Reports, 1976-1989). Measurement and sampling error were unavailable, and are likely candidates for a research paper devoted solely to that topic. Further discussion of the possible relationship of each river covariate to adult survival has been included in the data section (2.1) to warrant its inclusion in the analysis. Hanford Reach emigrants were not part of this study, only releases from Priest Rapids were used.

The problem of synchrony and a partial solution is discussed in the methods section, page 11.

The impression of negative correlation of turbidity to flow is due to the way turbidity is measured at McNary Dam. Using a secchi disk, a higher measured value (in feet) indicates less turbidity (the disk was visible at a greater distance through the water). Therefore, a negative correlation means that higher flows are associated with greater turbidity (and smaller measurements), and vice-versa.

page 13: Due to the length of time involved in this analysis, the suggestion of pooling of the downriver stocks into one group was not looked into. This would be an interesting avenue to explore.

Selection of stocks for comparison: Starting with all fall chinook CWT-tagged stocks on the river, selection of potential comparison stocks were based on the following criteria: 1) release dates: generally spring released stocks; 2) developmental stage: similar to Priest Rapids stock; and 3) production and/or index stocks (no experimental stocks). A matrix of the fraction of stock recovered by age and location were analyzed using SPSS cluster analysis. Brood years, recovery fractions and tag identification codes for the final reference stocks used in the analyses are listed in Appendix C.

page 14-15: Equation added back into the document.

page 15: Additional information added about the chi-square homogeneity test (See "3. 1.2 Ocean Distribution Analysis" on page 27.).

page 22, **Table 4:** Euclidean^2 column removed.

page 25, text and Table 7: Table headers now include time periods of covariate correlations. All three correlation tables now have an indicator of significance ***(a c* 0.05)** of correlation different from zero, calculated using the Pearson's product moment correlation coefficient test.

page 25, **Table 7: Flow** and turbidity appear to be negatively correlated, as turbidity is measured by secchi disk, which records the distance of visibility. Higher turbidity is indicated by lower values, the opposite of flow, which is recorded as cubic feet per second.

page 25, **last sentence:** Temperature may be more of an important factor than the other river covariates used in this analysis, and thus its inclusion in many of the models. The sentence commenting on temperature correlation was removed, due to the fact that though the correlations are less than other factors, they are still significant after applying the Pearson's product moment correlation coefficient test for difference from zero.

Section 3.3.5: In order to publish the analysis quickly, it was decided that it would be better to incorporated the previous manuscript as an appendix (Appendix A) due to logistics of word-processing, editing, etc.

Discussion: The Discussion section has been edited to remove the redundancy noted, and be more to the point on the finding of this analysis. Comparison of results to other studies is not appropriate in this case, as any seeming relationships determined in the covariates to survival are questionable, due to the inability to sufficiently account for marine effects.